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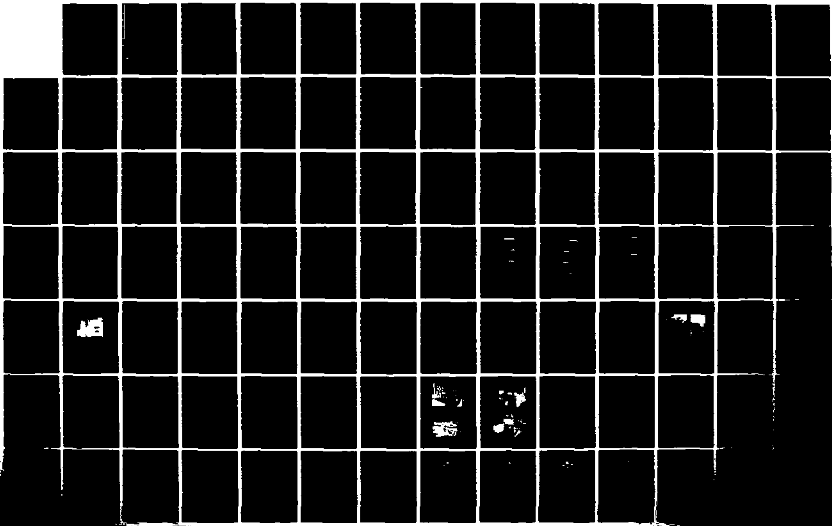

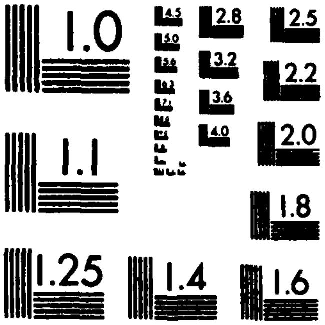

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AD-A143 845

DEVELOPMENT OF ACCELERATED FUEL-ENGINE QUALIFICATION PROCEDURES

FINAL TECHNICAL REPORT
No. SwRI-6797/4

By

John A. Russell
J. P. Cuellar, Jr.
R. A. Alvarez
Fuels and Lubricants Research Division
Southwest Research Institute

and

R. L. Rentz and T. J. Timbario
Mueller Associates, Inc.
Baltimore, MD

Under Contract to

U.S. Army Belvoir Research and Development Center
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Shale Fuels	Thermal Stability	Bench Test
Coal Fuels	Elastomer Compatibility	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Activities and findings are described for a 24-month program aimed at the development of procedures for accelerating the qualification of new fuels on Army equipment, emphasizing those derived from oil shale and coal. Principal activities were the development of bench and component test methodology for specific testing of properties peculiar to non-petroleum derived liquid hydrocarbon fuels not now covered under present federal or military fuels specifications. Laboratory test method development entailed modification of the a Jet Fuel Thermal Oxidation Tester (JFTOT) to evaluate not only thermal stability but elastomer compatibility

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by incorporating a heated reservoir to examine fuel effects on elastomer swell and hardness change as well as elastomer leachate on thermal stability. Lubricity evaluations entailed the application of the Ball-on-Cylinder-Machine (BOCM). Diesel injector pumps were subjected to 300-hour endurance testing using a recirculatory fuel loop and maintaining the lubricity of the fuel at very poor levels by clay filtration.

EXECUTIVE SUMMARY

This report covers technical activities for FY1982-1983 under the stated contract to develop test methodologies for the U.S. Army Accelerated Fuel-Engine Qualification Procedure (AFQP). During the past ten years, the worldwide shortage of petroleum fuels, followed by the emergence of a promising synfuels industry, has caused Department of Defense technical staff to be concerned with (a) the performance and specific properties of hydrocarbon fuels derived from non-petroleum resources and (b) the degree to which hydrocarbon fuels, whether petroleum, shale or coal-derived can be permitted to deviate from specification requirements without sacrifice in performance, endurance or maintenance of military tactical and combat surface and air vehicles.

In the qualification of any liquid hydrocarbon fuel for military use, the candidate fuel must pass through a series of tests, ranging from compositional analysis to laboratory bench and engine testing and subsequent fleet testing. Laboratory bench testing can take days, perhaps weeks; full-scale engine dynamometer testing weeks, perhaps months; a properly designed field fleet test program will require from 1 to 3 years.

It is the purpose of the AFQP to strengthen the "front end" (laboratory) portion of the test series so as to eliminate the time-consuming and expensive engine dynamometer and fleet test portions of the fuels qualification sequence.

In order to do this, it is obligatory to identify properties and characteristics peculiar to non-petroleum or non-specification fuels and to develop corresponding

screening tests and criteria to provide designers and operators of military powerplants adequate information to decide whether candidate fuels are appropriate for specific military applications.

The key aspects of the AFQP are:

- Critical (fuel-sensitive) engines/components identification and listing for use in AFQP test method development..
- Generation of a wide spectrum of liquid hydrocarbon test fuels formulated to be as representative of "future fuels" as possible.
- Bench and component testing of the above family of test fuels to adapt existing apparatus and procedures to AFQP needs and to identify tentative repeatability and pass/fail criteria.
- Full-scale engine probing and endurance testing (not performed under this present contract, but to be initiated at AFLRL in FY1984).
- Correlation analyses (where possible) between fuel properties and fuel performance in lab, bench, and engine testing (to be initiated at AFLRL in FY1984).

In pursuing these activities over the past two years, the test fuels have been employed to adapt **existing** widely-used bench tests for **thermal stability, elastomer compatibility, lubricity and corrosion.** These are considered to be the most likely key properties which new fuels may have which are not now covered by military or federal specifications and yet which may cause field problems. In addition to bench tests covering these properties, a Component Endurance Test Facility (CETF) has been

designed, fabricated and developed to test four most prevalent and important diesel fuel pumps for **endurance** (wear and elastomer compatibility) since these pumps were considered to be the most fuel-sensitive items in Army vehicle fuel systems. Test methodology and pass/fail criteria for this activity have been intended to identify one or two such fuel injector pumps for the evaluation of new fuels to provide correlative data with the above-mentioned bench tests. In developing this **test methodology,** a shale marine diesel fuel (Paraho-II DFM) maintained at low lubricity by clay filtration has been employed extensively in the components evaluation phase.

As an illustration of the amount of fuel, time and money which can be saved by the acceleration (shortening) of new fuels evaluation, Table 1 presents a **hypothetical summary estimation** of fuel consumption as well as **time estimates and assumptions for present qualification testing procedures.** "Fuel Consumption" (gallons/hour) and "Fuel Economy" (miles/gallon) are listed for the 11 most prevalent/critical engine models, together with the numerous tactical and combat vehicles which they power. Two of the most widely used engine dynamometer cyclic endurance tests currently used for **engine qualification** are (a) the **NATO 400-hr cycle** and (b) the **500-hr Mission Cycle test.** These cycles have been used for engine qualification and would be logical candidates for AFQP testing as well.

The values for "Fuel Consumed Per Test" (columns 4 and 5) are obtained by merely multiplying the individual "Fuel Consumption" (gallons/hr) by 400 and 500, respectively. This is, admittedly, an approximation, since fuel consumption will likely differ for the two cycles. It does, however, provide a reasonable <u>estimate</u> of 85,560 gallons of test fuel for 11 NATO cycle fuel qualification tests <u>or</u> 106,950 gallons for 11 Mission Cycle tests.

TABLE 1. FUEL CONSUMPTION ESTIMATES FOR ENGINE DYNAMOMETER & FLEET TESTING

Engine Model	Vehicle Application	Fuel Consumption (gal./hr)	Fuel Consumed Per Test, Gal. NATO 400-hr* Cycle	Fuel Consumed Per Test, Gal. 500-hr* Mission Cycle	Fuel Economy (mpg)**	Total Fuel Consumed For A 1-Year, 25-Vehicle Fleet Test, Gal. (Miles/year/Vehicle)***
AGT-1500	M1 Tank	56	22,400	28,000	0.81 (M1)	48,950 (1,586)
AVDS-1790	M485, M60A1, M60A1, (RISE) M60A2, M60A3, M88A1, M728	34	13,600	17,000	0.89 (M60A1)	21,601 (769)
VTA-903T	M2, M3	28	11,200	14,000	1.7 (M2)	23,324 (1,586) (M2, M3 not available at th time; M1 mileage used)
8V71T	M108, M109, M109A1, M109A2, M109AA3, M110, M110A1, M110A2, M578	21	8,400	10,500	1.4(M578)	13,589 (761)
6V53	M106A1, M113A1, M125A1, M132A1 M548, M577A2, M667, XM727, M730 M741, XM806E1	12.5	5,000	6,250	3.2(M113A1)	7,672 (982)
LD-465-1 LD-465-1C LD-465-1C	M35AS, M35A2, M36A2, M44A2, M45A2, M45A2C, M46A2, M46A2C M49A2C, M50A2, M50A3, M109A2, M185A3, M275A2, M292A2, M392A5	9.3	3,720	4,650	6.0(M35A2)	9,304 (2,233)
LDS-465-1 LDS-465-1A	M40A2C, M51A2, M52A2, M54A2, M54A2C,M55A2, M61A2, M63A2, M63A2C, M246A2, M291A2, M291A2C, M291A2D, M328E2, M543A2, M738E2, M748A2	10.8	4,320	5,400	4.8(M54A1C)	8,313 (1,596)
LD-465-(TC)	M656	21.7	8,680	10,850	2.2(M656)	36,943 (3,251)
NHC-250	M813, M813A1, M814, M815, M816 M817, M818, M819, M820, M821	12.0	4,800	6,000	4.0(M813)	19,581 (3,133)
GM-6.2 (Diesel)	CUCV	5.2	2,080	2,600	17.0(CUCV)	8,978 (6,105) (CUCV not available at time; M880 mileage used)
L141	M151, M151A1, M151A1C, M151A2, M825, M718, M718A1	3.4	1,360	1,700	19.1(M151)	4,398 (3,360)
			85,560	106,950		202,653

* Per engine test (about 6-8 weeks per test including pre- and post-test inspections)
** Source: TM43-0001-31, "Equipment Data Sheets for TACOM Equipment", 1978.
*** Source: "Fleet Management Data Combat Vehicles Average Usage and Age" and "Fleet Management Data Tactical Vehicle Average Usage and Age", U.S. Army DARCOM Materiel Readiness Support Activity, 22 April 1983 (For period 1 Nov. 1981- 1 Nov. 1982)

The several entries in the last two columns are for a **presumed 1-year fleet test of 25 vehicles** of each of the types parenthetically identified under "Fuel Economy" (column 6). Correspondingly, the average utilization (mileage)* of these vehicle types is shown parenthetically in column 8. Calculation of "Total Fuel Consumed" (column 7) is made by:

$$\text{Total Fuel Consumed} = \frac{\text{Miles/year/vehicle}}{\text{(miles/gallon)}} \times 25$$

For example, for the **M35A2:**

$$\text{Total Fuel Consumed} = \frac{\text{2,233 miles/year}}{\text{6.0 miles/gal}} \times 25$$

9,304 gallons per year

If 25-vehicle fleet tests were performed for all 11 vehicle types at the assumed average utilizations (probably much lower than actual fleet testing would require), then a grand total of 202,653 gallons/year would be required.

Fleets greater than 25-vehicles tested for more than 1 year at higher utilization rates would, of course, elevate this **purely illustrative estimate** dramatically. Certainly, not all vehicle types would be tested in a real-world situation.

Such arithmetic manipulations can be made to demonstrate any degree of test fuel savings. Of greater consequence would be the **cost and man-year savings** in planning, test fuels procurement/distribution logistics, workload increase (e.g., FORSCOM, Ft. Belvoir, and TACOM personnel), plus liaison and analysis of fleet test data.

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* By FORSCOM only, since this would be the logical organization to execute fleet tests.

Annual test fuel savings by fleet test elimination might run \$1-5 million (since test fuel batches blended to stringent control criteria are expensive). Estimates of cost and time savings from reduced fleet test requirements would certainly run several times that amount.

FOREWORD

This work was conducted at Southwest Research Institute (SwRI), San Antonio, Texas, under contract DAAK70-81-C-0209 during the period October 1981 through September 1983. The work was funded by the U.S. Army Belvoir Research and Development Command, STRBE-VF, Fort Belvoir, VA. Dr. J.V. Mengenhauser, Materials, Fuels, and Lubricants Laboratory, STRBE-VF, Fort Belvoir, VA, served as Contracting Officer's Representative.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF ILLUSTRATIONS

I. INTRODUCTION

A. Background

The overall Army fuels R&D program has been described in previous documents (*1,2). The objective of this present program is **"to develop test methodology and criteria <u>specific to the peculiarities of synthetic fuels</u> which can be integrated into an accelerated qualification screening test series ranging from compositional analysis to bench and component testing to full-scale engine dynamometer testing."** Figure 1 depicts the major activities incident to the parallel processes of engine and fuel qualification. These must now be considered as an **integrated system.** The thrust of this present program is to develop bench and component test methodologies which will <u>strengthen</u> the front end of the test series. If sufficient confidence in laboratory qualification procedures and criteria can be developed, time-consuming and costly field evaluations can be eliminated.

B. Approach

To accomplish this goal, the following activity areas were undertaken:

- List, categorize, and rank key Army tactical and combat surface vehicles together with their engine and fuel systems to identify critical fuel-wetted components as candidates for use in the qualification of new candidate fuels.

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* Numbers in parentheses refer to List of References

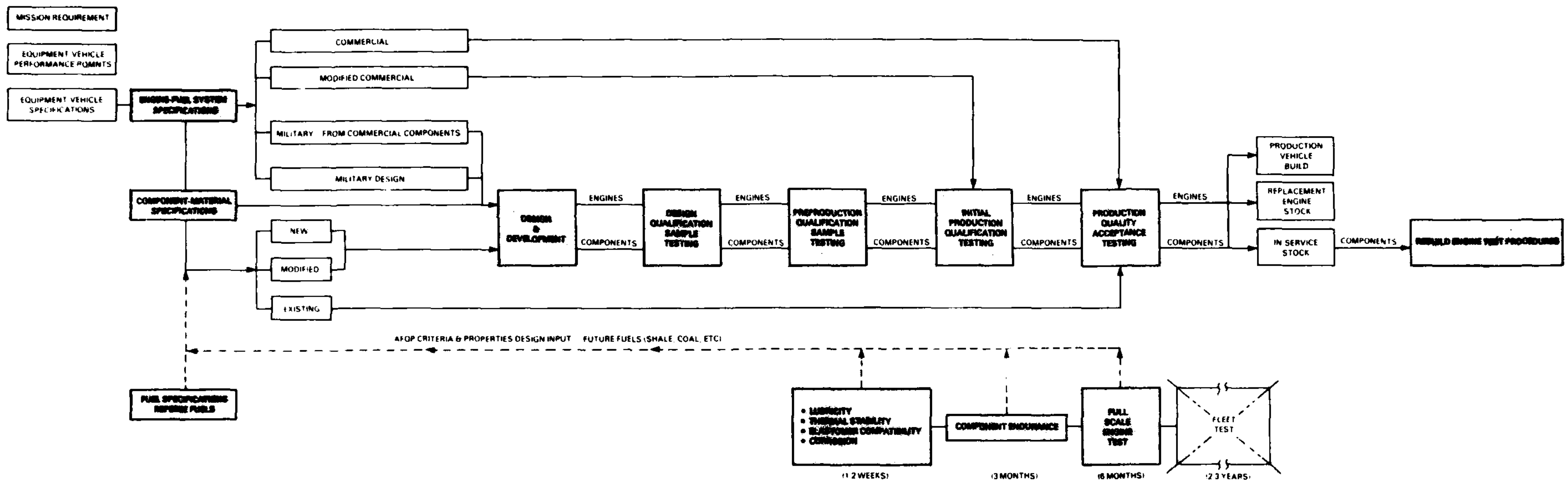

FIGURE 1. ACCELERATED FUELS QUALIFICATION PROCEDURE (AFQP)

- Evaluate existing engine/component qualification procedures to assess their relevance to new fuels.
- Define the physical properties and chemical compositions of an envelope of future fuels derived from non-petroleum fossil resources (principally oil shale and coal) and identify characteristics which these fuels may not have in common with present Military Specifications quality petroleum fuels
- Where possible, utilize actual shale- and coal-derived distillate and gasoline fuels for bench and component testing. In this context, the Paraho-II (circa 1978) DFM and SASOL II diesel and gasolines have served as the test fuels for the physical portion of this program.
- Plan and execute a coordinated **test method development program** as well as a **candidate verification testing sequence** for procedures deemed applicable in screening new fuels

C. Summary of Accomplishments

Details of the following key accomplishments during this contract will be presented in subsequent sections of this report. Briefly, these are:

- Identification and listing of key tactical and combat **mobility** equipment with subcategorization of engine types
- Identification of all fuel-wetted elastomer types in the above equipment
- Corresponding identification of all fuel-wetted metals in the above equipment
- Selection and rationale for ranking of key Army tactical and combat diesel powerplant and injector systems
- Identification and rationale for candidate full-scale engine qualification procedures

- Development of test methodology for component endurance testing including a Component Endurance Test Facility (CETF)
- Development of bench test methodology for lubricity, thermal stability, elastomer compatibility and metals corrosion utilizing state-of-the-art shale-derived and coal-derived distillate and gasoline fuels
- Definition of repeatability for the above bench test techniques
- Bench and component testing of a wide variety of fuels, materials, and component combinations

II. THE AFQP CONCEPT

Army regulation 703-1 defines three fuel types:

- **Primary Fuel** - a fuel that meets full design performance.
- **Alternate Fuel** - a fuel that provides performance equal to the primary fuel but may be a restricted item of supply in tactical areas or has environmental limitations. No degradations of performance or service life occurs as a result of the use of an alternate fuel within the prescribed operational range.
- **Emergency Fuel** - a fuel used when the primary or alternate fuel is not available. The use of an emergency fuel may result in increased maintenance and/or reduced engine life. Severe performance derating is permissible when an emergency fuel is used, but it must not destroy the materiel within the operating period prescribed by the engine designer.

The AFQP can be thought of as a successive screening process whose objective is to determine in the shortest time frame and at least cost, the actions necessary to identify proper areas of utilization of a new fuel within the Army's inventory of existing engines and vehicles. The AFQP should ultimately classify new fuels into one of the above types. Since the distinction between primary and alternate fuels is logistical, not operational, there are really only two types: primary/alternate (full engine performance) and emergency (reduced performance). To these could be added another type: unacceptable (may damage or destroy the engine). The AFQP process will be intended not only to classify the new fuel but also to provide additional information such as:

- Additives which may affect the fuel type (e.g., upgrade unacceptable fuels into emergency fuels, etc).
- Maintenance and performance penalties incident to using an emergency fuel.
- Engines or components most tolerant of, or susceptible to, emergency fuels.
- Need for possible modification to fuel specifications (e.g., should VV-F-800 have a lubricity test or a requirement for a lubricity additive when the fuel has been hydrotreated).

The same AFQP information listed above could also be used in the decision-making process to waiver off-specification fuels (use of additives, maintenance or performance penalties, etc).

In developing an approach to achievement of the AFQP, several factors/questions have been addressed, including:

- Definition of a series of fuels for which upper and lower property limits can be determined as being representative of fuels most likely to be available in the future (for Army mobility).
- Definition of how well each engine and component test procedure determines acceptance or rejection (of ability to tolerate the limits of experimental fuel properties).
- Definition of pass/fail criteria and minimum acceptable confidence level, especially with regard to fuel properties or characteristics not contained in the VV-F-800 fuel specification.

- Definition of the extent and mix of bench-scale, component/subsystem-level, and full-scale engine testing, recognizing that the ultimate objective is to accelerate the entire qualification process to the greatest extent practicable.

In consideration of the above, two key elements define the approach to the AFQP. These elements are conceptually displayed in Table 2 and Figure 2. Table 2 illustrates "key fuel properties" expected to be of concern to Army diesel engines and related fuel system components. These properties are then related to "critical engine parameters" which are to be evaluated in terms of fuel property effects. The range of key fuel properties (in terms of upper and lower boundaries) is described for the fuels to be evaluated.

Note that these values have been arbitrarily nominated for <u>illustration</u>. Thus, the concept of evaluating fuel <u>properties</u> (as opposed to fuels) is established. Once the AFQP is established, it is envisioned that whenever a "new" fuel is to be considered for used by the Army, judgment of its performance can be determined rather rapidly by assessing where its properties lie in relation to the property limits evaluated under this program. If, for example, the viscosity of a "new" fuel falls within the range of the viscosity limits evaluated and found acceptable under this program, the critical engine parameters related to viscosity would be expected to be not adversely affected with the "new" fuel.

Table 2 further illustrates the approach to evaluating fuel properties via description of test level complexity as shown under the column titled

TABLE 2. AFQP FUEL/HARDWARE/TESTING APPROACH

Key Fuel Properties	Range of Key Fuel Properties: Upper	Range of Key Fuel Properties: Lower	Critical Engine Parameters	Testing/Evaluation Procedure: Bench	Testing/Evaluation Procedure: Component Subsystem	Testing/Evaluation Procedure: Engine
Viscosity @ 40°C, cSt	3.12	1.71	Fuel Delivery and handling	✓	✓	
Cloud Point, °F, (°C)	50 (10)	9 (-13)				
Pour Point, °F (°C)	5 (-15)	-29 (-34)				
Cetane No.	70.4	36.3	Initiation of Combustion			✓
10% Distillation Point, °F (°C)	465 (241)	398 (212)				
Copper Strip Corrosion, 3 hrs, 122°F (50°C)			Reliability/ Durability	✓	✓	✓
Carbon Residue, wt. %	0.16	0.04				
Aromatics, FIA, vol. %	50.9	10.6				
Lubricity (BOCM)	TBD	TBD				
Thermal Stability (TOFT)	TBD	TBD				
Sulfur Content, wt.%	0.49	0.00	Corrosion	✓	✓	✓
Aromatics, FIA, vol. %	50.9	10.6	Emissions			✓
N_2 Content, wt. %	0.0423	0.004				
Lubricity (BOCM)	TBD	TBD	Wear	✓	✓	✓
Particulates, mg/l	4.7	0.2				
Copper Strip Corrosion, 3 hrs 122°F (50°C)			Materials Compatibility	✓	✓	✓
Sulfur Content, wt. %	0.49	0.00				
TAN, mg KOH/g	0.15	0.01				

TBD To Be Determined

NOTE: Key fuel properties limits are TENTATIVE NOMINEES for illustration only.

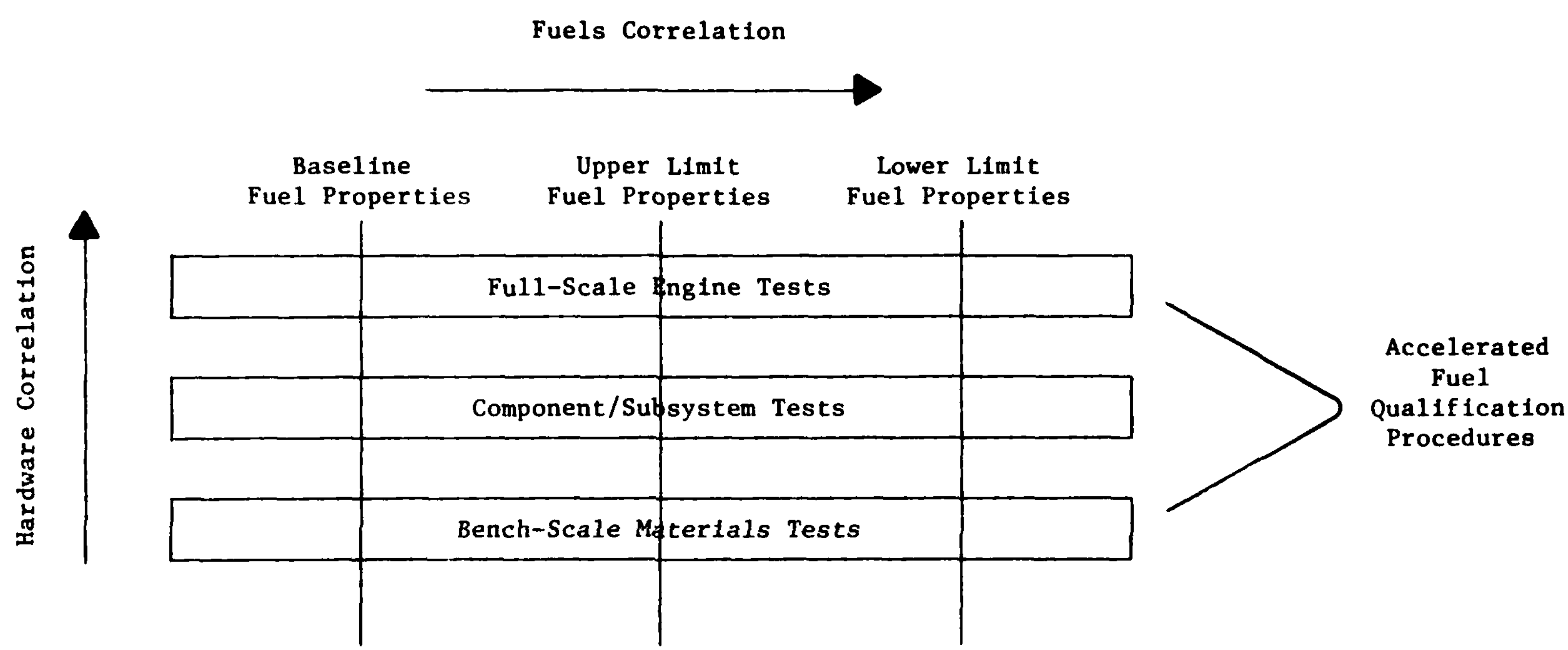

FIGURE 2. CROSS-CORRELATION APPROACH TO ACHIEVING AFQP

"Testing/Evaluation Procedure." Note that some fuel properties can be evaluated quite effectively with bench-scale tests. Table 2 will serve as a guide for future testing under this program. Part of the program, as will be discussed later, was to determine, without conducting full-scale engine tests, how well less-complex testing procedures can predict engine performance, thus satisfying a major goal in achieving the AFQP. Fuels exhibiting the range of properties shown in Table 2 are discussed and described elsewhere in this report.

Figure 2 illustrates the correlation concepts that must be addressed in the approach to AFQP development. Two correlations are required to be established. The first is to establish a hardware correlation between bench-scale, component/subsystem-level and full-scale engine tests for each fuel. The second is to establish a correlation between the properties of the baseline fuel (VV-F-800, Grade DF-2 Diesel Fuel) and those of the experimental fuels to be evaluated. The testing portion of this program has been designed to obtain those relationships and cross-correlations between them.

When the AFQP is established, its ability to pick detrimental fuel property effects on engine performance will be a test of its validity and usefulness. There are four possible outcomes that can result from application of the AFQP as shown on Figure 3. From Figure 3, the most highly desired are outcomes 1 and 2. Less desirable is outcome number 3, and least desirable is outcome number 4. The structure of this program and intent in developing the AFQP are to minimize the probability of outcome number 4 occurrence. While significant progress has been achieved to date, full-scale engine tests are required to complete the correlation

"process" and establish the AFQP as a viable discriminator of fuel-engine interactive affects. Such tests have not been accomplished to date, but are planned under future program activities.

1 Procedure predicts engine failure and engine failure occurs.	2 Procedure does not predict engine failure and failure does not occur.
3 Procedure predicts engine failure and failure does not occur.	4 Procedure does not predict engine failure failure does occur.

FIGURE 3. POSSIBLE OUTCOMES OF AFQP APPLICATION

Referring to the AFQP correlation concept explained earlier, initial development steps for the AFQP were based on fuel system testing procedures currently in use by engine and component manufacturers. With these existing procedures as a starting point, component and bench-scale data were acquired. Subsequent correlation of bench-scale and full-engine tests needs to be established. At that point, data can be fed back and assessed. New procedures or modifications to existing ones can then be assessed and developed as part of the AFQP in terms of the existing data base (with current specification quality fuels) and any new data generated under future program work. Overall, the approach was to start with "what we know," evaluate "what we find" under the testing portion of this program, and meld both into "what we want to achieve" as the AFQP. Component testing procedures have included, for example, cyclic tests of complete engine fuel systems to evaluate wear, durability, and materials compatibility under loaded conditions. As mentioned previously, full-scale engine tests are needed to complete the correlation and assessment work needed to fully establish the AFQP.

III. SwRI LABORATORY PROGRAM

A. General

Laboratory activities during this two-year period have entailed bench scale and component testing of the following key properties:

- Thermal stability
- Lubricity
- Elastomer compatibility
- Elastomer leachate effect on thermal stability
- Elastomer leachate effect on lubricity
- Component endurance (injector pump wear)
- Metals corrosion

The subsections which follow describe the detailed materials and procedures, together with discussions/interpretations of data.

B. Test Materials

1. Test Fuels

A variety of fuel types were utilized in this program in an effort, where possible, to cover the range of fuel types available for present and future use. Such categories included conventional petroleum-derived products, shale-derived materials, and coal-derived fuels. Some emphasis was placed on a Paraho-II shale diesel fuel because of the expected near-term field deployment of shale fuels, and because the product was the only synthetic fuel available in plentiful supply.

Six hydrocarbon products served as the primary fuels for laboratory three study -- diesel fuels and three broadcut fuels. Broadcut fuel (BCF) is a wide boiling range product with no octane or cetane requirements for use in future, fuel-

tolerant engines. Within each fuel category, diesel or BCF, one fuel was a typical petroleum product, one a shale-derived product, and one based on coal-derived fuel. Diesel fuels included Cat 1-H (DF-2), a widely used petroleum reference fuel; Paraho-II DFM, which also meets DF-2 specification requirements; and a medium cetane SRC-II/petroleum blend. The three BCF products were all laboratory blends prepared in accordance with findings resulting from a Department of Energy study [3] on synthetic fuels for highway transportation. The medium cetane SRC-II diesel fuel blend was also prepared on the basis of that work.

Table 3 lists the compositional makeup of the six primary fuels, along with physicochemical property data. It is emphasized that only the Paraho-II DFM fuel represents a "pure" synfuel product. All other synfuels were laboratory-prepared formulations containing syncrude portions. This approach was necessitated by the highly limited availability of finished, specification-quality synfuels. In this regard, special mention should be made of the coal BCF which consists mainly of petroleum heavy straight-run (HSR) naphtha and a simulated coal light straight-run (LSR) naphtha. The latter fraction was prepared by adding pure tetralin and decalin and a coal-derived tetralin solution to HSR naphtha from petroleum. The tetralin solution (coal) includes a variety of compounds, shown as follows:

	Volume Percent
Toluene	0.5
Ethylbenzene	9.5
p-Xylene	0.6
o-Xylene	0.6
Tetralin	39.6
Naphthalene	18.8
Indene and tetramethylbenzenes	29.4
Total	100.0

TABLE 3. PRIMARY TEST FUELS

Fuel Code AL- Fuel Type	10115 Petro Cat 1-H	10150 Paraho-II DFM	10289 SRC-II, Med. Cetane	10286 Petro BCF	10305 Shale BCF	10306 Coal BCF
Composition, vol%						
LSR naphtha	---	---	---	40	32	39.9
HSR naphtha						
Petroleum	---	---	---	26.9		---
Shale	---	---	---	---	35	---
Coal (sim)	---	---	---	---	---	45.8
Kerosene						
Shale JP-8	---	---	---	---	10	---
Diesel Petroleum	100	---	65	19.7	7.7	---
Shale DFM	---	100	---	---	---	---
Coal SRC-II	---	---	35	---	---	---
Light Cycle Oil	---	---	---	11.8	11.5	11.4
n-Butane	---	---	---	1.6	3.8	2.9
Properties						
Gravity, API, 60°F	34.9	37.9	26.8	51.4	53.2	55.4
Specific Gravity, 60/60°F	0.8509	0.8353	0.8939	0.7736	0.7661	0.7571
Distillation, °F, D 86						
IBP/5% Recovered	400/430	402/435	346/409	89/121	81/92	81/97
10/20	448/468	452/470	424/446	133/157	117/157	117/143
30/40	482/494	482/497	464/476	181/207	200/242	167/188
50/60	508/520	508/521	489/502	237/291	280/318	210/235
70/80	530/547	533/547	522/543	484/534	355/438	268/325
90/95	560/571	563/575	577/610	590/644	542/600	435/570
EP	584	593	638	662	634	615
Recovery, %	99.0	99.0	98.5	96.0	96.5	96.0
Residue	1.0	1.0	1.2	1.5	1.5	1.5
Reid Vapor Pressure, lb	---	---	---	9.2	9.8	9.9
Viscosity, cSt, 40°C	3.12	2.60	2.83	0.79	0.72	0.59
Pour Point, °F (°C)	5(-15)	0(-18)	0(-18)	-22(-30)	-52(-47)	-76(-60)
Hydrocarbon type, vol%						
Aromatics	32.8	30	49.5	16.4	14.8	15.3
Olefins	2.7	1	1.8	0.0	0.3	0.0
Saturates	64.5	69	48.7	83.6	84.9	84.7
Elemental analysis, wt%						
Carbon	86.46	86.54	86.03	85.89	85.65	85.96
Hydrogen	13.09	13.36	11..47	13.71	13.91	13.76
Oxygen	---	0.33	---	---	---	---
Nitrogen	0.0004	0.022	---	---	---	---
Sulfur	0.4	0.004	0.33	0.31	0.31	0.30
H/C Atom Ratio	1.81	1.84	1.59	1.90	1.94	1.91
Heat of Combustion						
Gross, BTU/lb	19,860	19,537	18,950	20,445	20,345	19,990
MJ/kg	46.20	45.44	44.09	47.56	47.32	46.50
Net, BTU/lb	18,665	18,318	17,904	19,194	19,076	18,735
MJ/kg	43.42	42.60	41.64	44.65	44.37	43.58
Accel. Stability, mg/100ml	0.09	0.20	Plugged Filter	---	---	---
Steam Jet Gum, mg/100ml	---	0.0	100.9	---	---	---
Cetane Number	48.6	48.9	31.4	31.1	30.9	25.0

Some experimental work was also performed with two Sasol coal-derived fluids, one gasoline and one diesel fuel. Table 4 lists property data for two finished products supplied by Sasol Technology (Proprietary) Limited, Republic of South Africa. Sasol described the gasoline as "of 93 RON and is called premium and not regular because it is sold in areas which are at least 4000 ft above sea level". No unusual property values are noted for the gasoline except Reid vapor pressure is somewhat low, even if intended for summer use. A low vapor pressure requirement may be a consequence of the fuel's use only at higher elevations.

Relative to the VV-F-800 Federal Specification for DF-2, the Sasol diesel product would not be acceptable because of high distillation temperatures for 90 percent recovery and end point. Cloud and pour points are also relatively high, causing the fuel to be unacceptable (per VV-F-800) for use in Europe and much of the continental U.S. in winter months.

One additional fuel was employed in the program for a component endurance test. This was a petroleum JP-5 fuel (Code FL-0203-T) which exhibited poor lubricity characteristics (as evidenced by Ball-on-Cylinder Machine tests) as received from the refiner. As a consequence, the fuel was used as the test fluid in one endurance run with a 6V53/T engine fuel pump (to be described in subsequent section of this report).

2. Elastomers

Four elastomer types were utilized in the bench-test program. These represent the most widely used elastomer types in Army surface and air mobility vehicles. They were:

TABLE 4.
SASOL FUEL PROPERTIES

Fuel Code Fuel Type	FL-0229-G Sasol II Gasoline	FL-0230-F Sasol II Diesel
Gravity, °API, 60°F	62.5	44.5
Specific gravity, 60°/60°F	0.7301	0.8040
Distillation, °F, D 86		
IBP/5% recovered	93/115	374/390
10/20	128/147	392/402
30/40	164/183	410/422
50/60	205/231	434/452
70/80	258/285	480/532
90/95	315/330	643/737
End Point	396	760
Recovery, %	98	99
Residue, %	1.0	1.0
Reid vapor pressure, lb	7.8	---
Viscosity, cSt, 40°C	---	2.09
Pour point, °C (°F)	---	-15 (5)
Cloud point, °C, (°F)	---	8 (46)
Flash point, °C, (°F)	---	71 (160)
Cu strip corrosion	1a	1a
Hydrocarbon type, vol%		
Aromatics	20.5	24.0
Olefins	21.6	0.0
Saturates	57.9	76.0
Elemental analysis, wt%		
Carbon	85.4	85.7
Hydrogen	13.8	14.0
Nitrogen	0.001	0.001
Oxygen	---	0.01
Sulfur	0.01	0.01
Lead, g/gal	1.97	---
Heat of combustion, net		
BTU/lb	19,137	18,884
MJ/kg	44.51	43.92
Existent gum, D 381, mg/100mL		
Unwashed	3.2	---
Washed	1.9	24.4
Oxidation stab., D 525, minutes	1440	---
Acclerated stability, mg/100 ml	---	0.78
Particulates, mg/L	---	0.8
Octane number		
Research	92.7	---
Motor	84.5	---
Cetane number	---	50.1
Trace metals	---	Nil

- Fluorocarbon (Viton)
- N219-7 Acrylonitrile/butadiene
- Buna N70 acrylonitrile/butadiene
- Fluorosilicone

These three generic classes (N219-7 and Buna N70 are buna type materials reasonably close in composition and properties) and are used in both diesel and turbine fuel systems in static and dynamic applications. Elastomer coupons were procured in the form of ½" OD O-rings and their utilization will be described immediately below.

C. Bench Test Program

1. Thermal Stability/Elastomer Compatibility

This part of the program measured (a) deposit-forming tendencies of the fuels, (b) degradative effects of the fuels on the elastomers (swell and hardness change), and (c) elastomer leachate effect on a given fuels deposit-forming tendency as compared to the neat fuel.

All thermal stability and elastomer compatibility testing was performed in the Thermal Oxidation Fouling Tester (TOFT) which is essentially a Jet Fuel Thermal Oxidation Tester (JFTOT) with a few added capabilities [(2)]. Of these, only the heated reservoir (66°C) was employed in elastomer evaluations. Otherwise, standard JFTOT test conditions* were used with the exception of max preheater tube temperature. These conditions were:

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* JFTOT procedure per ASTM D3241.

- 3 ml/min fuel flow rate
- 150-minute test duration
- Standard aluminum preheater tube and stainless steel test filter
- Preheater max tube temperature control at any selected temperature for the 150-minute duration

JFTOT measurement techniques and analysis have been described elsewhere [2], and can be summarized as follows:

Deposits on an aluminum preheater tube are rated visually from "Code 0" (polished aluminum) to "Code 4" (heavy dark brown) and by a "Tube Deposit Rater" (TDR) which is a device measuring visible-band reflectance from a calibrated light source off the preheater tube to a very sensitive light meter. The readout scale is calibrated from 0 (polished aluminum) to 50 (heavy dark brown). The two techniques correlate reasonably well, with the exception of those deposits which give a "rainbow" or "peacock" to which the TDR is indifferent. The second rating criteria for the JFTOT method is pressure drop across a small filter element. If particulate matter is carried downstream from the preheater section (or if catalytic action causes deposits to form on the filter element proper), there will be an increasing pressure differential (ΔP) during the 150- minute JFTOT test. Many of the thermal stability specifications (either commercial or military) restrict ΔP to about 25 mmHg maximum. Further, the apparatus itself is normally allowed to run for the full 150 minute test duration and, if filter ΔP exceeds 125 mmHg a bypass is opened so that the full test duration may be accomplished. For this reason in several of the following tables filter ΔP will be referred to as "125/82" or "0/150". This simply means that in the first

case the bypass valve was opened at 82 minutes when 125 mmHg was reached and in the second place no ΔP was observed for the entire 150 minute duration. An entry of "125/6" would indicate that the filter fouled quite rapidly (in six minutes) and an entry of "10/150" would indicate that only 10 mmHg was reached during the 150 minute test.

Standard JFTOT runs were first made at 25°C reservoir temperature. These were followed by TOFT runs (reservoir temperature 66°C). For baseline comparison, two subsequent runs were performed in which three elastomer coupons (of a single type) were placed in the reservoir. Because of their poor performance, certain of the fuels tested were subjected to clay treatment (either single or double pass) through a clay column.

The experimental work was essentially broken up into four separate studies. Although all of these are interrelated, they will be described and discussed individually below.

a. Diesel/Broadcut/Reference Fuel Evaluations

In this experimental sequence, 10 fuels or special fuel blends were employed. These were:

- AL-10115, petroleum Cat 1-H
- AL-10150, Paraho II DFM
- AL-10289, SRC II medium cetane
- AL-10286, petroleum broadcut fuel
- AL-10305, shale broadcut fuel
- AL-10306, coal broadcut fuel
- Neat iso-octane

- 70% iso-octane/30% toluene
- 60% iso-octane/40% toluene
- 50% iso-octane/50% toluene

Table A.1* presents JFTOT/TOFT summary data for all thermal stability baseline testing, i.e., 25°C sump temperature and 260°C max tube temperature (standard JFTOT) <u>or</u> 66°C reservoir temperature and 260°C max tube temperature (standard TOFT). None of these tests included immersed elastomers, but were run for comparison to subsequent elastomer compatibility testing. As regards preheater tube deposits for both JFTOT and TOFT testing, the petroleum Cat 1-H reference diesel fuel (AL-10115), the SRC II medium cetane fuel (AL-10289) and the shale broadcut fuel (AL-10305) gave by far the heaviest deposits. This was equally true of thermal stability as measured by filter fouling. The same three fuels plugged the test filter in relatively rapid order. Attempts to improve thermal stability characteristics by means of single-pass clay treatment were successful for the petroleum Cat 1-H reference diesel fuel but unsuccessful for the SRC II medium cetane and shale broadcut fuels. Even double clay treatment resulted in no improvement for the SRC II medium cetane fuel.

It is important to mention that a general rule of thumb for (static) elastomer seals is that hardness change will probably not affect their functions until it increases more than 10 Shore A points.+ Similarly, percent swell should not decrease more than 10 percent (i.e., <u>shrink</u>).++ **This is, of course, <u>extremely</u> design-specific and is based**

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* Note: Tables A.1 through A.16 are presented in Appendix A.

\+ Shore A hardness as measured by ASTM <u>D2240</u> technique.

++ Rubber swell as measured by ASTM <u>D471</u> technique

solely upon conversations with industrial designers, elastomer manufacturers, and government materials laboratory personnel. Static seals may function effectively after softening, but may not after hardening; they will likely function after swell, but may not function after some shrinkage.

Tables A.2 and A.3 present TOFT results when three elastomer O-rings were placed in the heated reservoir and tests run under standard TOFT conditions.* These O-rings were ½" OD by 1/8" thick. Because of their aforementioned poor thermal stability characteristics, there were no identifiable elastomer effects on the Cat 1-H diesel fuel and the SRC II medium cetane distillate. The Paraho DFM had virtually no effect as regards leachate impact on thermal stability. The petroleum broadcut fuel (AL-10286) had a pronounced effect upon the filter fouling characteristics, presumably due to the elastomer leachate for all four elastomers tested. This was also true of the simulated coal broadcut fuel (AL-10306) but not for the shale broadcut fuel (AL-10305).

Tables A.4 through A.11 present percent volume swell and Shore A hardness change for the triplicate O-ring coupon combinations of each elastomer and fuel after TOFT testing. The Buna N materials (N-219-7 and Buna-N-70) were by far the most susceptible to swell and hardness change, the most extreme changes being for these two elastomers immersed in the AL-10289 SRC II medium cetane fluid which, as described previously, contained 35% of the highly aromatic SRC II medium distillate bringing total aromatics to 49.5%. Average volume swell for N-219-7 elastomer was 44.1% and hardness change was -21.0 points; correspondingly, for the same fuel, Buna

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* Only a single elastomer type was used in each test.

N-70 averaged volume swell was 36.5% while (surprisingly) the hardness change was only -3.0 points. The other elastomer materials tested (Viton and fluorosilicone) reflected relatively small volume swell and hardness changes.

Table A.12 presents thermal stability data for special fluid blends ranging from neat iso-octane to 50/50 blends of iso-octane with toluene. The first entry in each block in Table A.12 is a baseline test (standard TOFT conditions, 66°C reservoir temperature). Preheater tube deposits for all baseline cases were essentially negligible as was filter fouling. This was also true when fluorosilicone O-rings were introduced. Again, the Buna N-219-7 and Buna N-70 elastomers exhibited sensitivity to the presence of toluene as measured by filter fouling.

Elastomer swell and hardness change data for these special blends are given in Tables A.11 through A.16. As with thermal stability, the Buna N-219-7 and Buna N-70 elastomers exhibited significant volume swell and hardness changes in those fluids containing toluene. This is taken as correlative evidence of the sensitivity of the Buna N type materials to fuels containing significant amounts of certain aromatic compounds and is considered important because of the great number of Buna N fuel-wetted seals in Army systems.

b. <u>SASOL II Gasoline and Diesel Fuel</u>

Two coal derived fuels of interest to the AFQP program were obtained from the South African Sasol II facility. Properties of these have already been given in Table 4. Standard JFTOT procedures (ASTM D3271) were employed to evaluate the Sasol II gasoline and diesel fuel. Table 5 presents thermal stability results for these two coal derived fuels. A <u>blue</u> deposit (corresponding to <u>about</u> a visual code 1 rating)

TABLE 5.
TOFT THERMAL STABILITY RESULTS FOR SASOL FUELS
(25°C SUMP; ASTM D 3241)

Max Tube Temp, °C	Tube Deposit Rating: Visual	Tube Deposit Rating: Spun	Tube Deposit Rating: Spot	Filter ΔP, mm Hg/minutes
	Sasol Gasoline (FL-0229)			
260	Blue	13	15	125/42
260	Blue	17	22	125/42
	Sasol Diesel (FL-0230)			
260	0	2	5	0/150
275	3	30	37	0/150
275	3	36	42	0/150
275	3	31	35	0/150
275	3	25	31	0/150
275	3	21	31	0/150
288	4	47	48	0/150

was obtained for the gasoline along with corresponding moderate reflectance ratings (TDR). Test filter fouling occurred in less than 1 hour (125 mm/Hg in 42 minutes for both tests), which is typical of any gasoline tested under standard JFTOT methods, whether petroleum, coal, or shale-derived.

The Sasol II diesel fuel performed well at the standard 260°C max preheater tube temperature. A Visual Code 0 rating was obtained, corresponding to TDR spun and spot rating of 2 and 5, respectively. No filter fouling was encountered. This is typical of <u>extremely high quality</u> diesel fuels.

Five replicate tests at 275°C max preheater tube temperature were then run on the diesel fuel to generate precision data for repeatability calculations (see subsequent section). These resulted in consistent visual code 3 ratings together with spun and spot TDR ratings ranging from 21 to 36 and 31 to 42, respectively. Again, no test filter fouling occurred. Maximum preheater tube temperature was then increased for one test to 288°C with a resulting visual code 4 and TDR spun and spot ratings of 47 and 48, respectively. Still, no filter fouling occurred.

In general, it may be concluded that the thermal stability properties of the two Sasol II fuels are quite comparable to those encountered for their typical petroleum counterparts of high quality.

Table 6 presents thermal stability data using TOFT (66°C reservoir) procedures to evaluate the effects of the Sasol II gasoline and diesel fuels on principal Army elastomers and correspondingly to measure the effects (if any) of

TABLE 6.
EFFECT OF ELASTOMERS ON SASOL FUEL THERMAL STABILITY
(260°C TUBE, 66°C SUMP)

Elastomer	Tube Deposit Rating: Visual	Spun	Spot	Filter ΔP, mm Hg/minutes
	Sasol Gasoline (FL-0229)			
None	1	5	7	125/ 42
Viton	2	12	17	125/121
N219-7	2	23	29	125/ 12
Buna 70	White	39	41	125/ 11
Fluorosilicone	2	21	22	125/ 33
	Sasol Diesel (FL-0230)			
None	2-3	17	26	0/150
Viton	1-2	7	8	0/150
N219-7	1	5	7	0/150
Buna 70	1	0	2	0/150
Fluorosilicone	3	23	37	0/150

elastomer leachate upon thermal stability as compared to baseline data. Again, fluorocarbon, N-219-7, Buna N 70 and fluorosilicone were employed.

The gasoline (FL-0229) showed some minor effects of leachate from the several elastomers upon preheater tube deposits. Baseline visual rating was Visual Code 1, with spun and spot TDR ratings of 5 and 7 respectively. With elastomers present, the Visual Code increased slightly to Code 2 (in one case a peculiar white deposit for Buna N 70 which is not equatable to the standard ASTM Visual Code) and somewhat increased spun and spot TDR's ranging from 12 to 41, depending upon the elastomer. Filter fouling was essentially the same for baseline and elastomer tests.

The Sasol diesel fuel (FL-0230) provided somewhat confounding results in that the baseline tests gave poorer visual spun and spot ratings than did some of the tests with certain elastomers. These can be seen in Table 6, the exception being for the fluorosilicone which gave a somewhat higher visual spun and spot rating. This may be an effect due to the increased sump temperature (66°C). Neither the baseline nor any of the elastomer tests caused any test filter fouling. As will be seen in subsequent subsections, the relatively high baseline TDR ratings were repeatable.

Elastomer compatibility data for the Sasol fuels are given in Table 7. The Viton materials showed the lowest volume swell, particularly for gasoline which would be expected, probably due to the higher concentration of low molecular weight aromatics. Average hardness change for both the Sasol gasoline and diesel fuel is considered to be negligible. Volume swell for the diesel fuel is also negligible. The only data considered considered marginally significant might be for the gasoline volume swell for N-219-7, Buna 70 and fluorosilicone, since any swell greater than 10% is generally considered to be a potential problem.

TABLE 7.

ELASTOMER COMPATIBILITY DATA FOR SASOL FUELS

(260°C TUBE; 66°C, SUMP)

Elastomer	Average* Volume Swell, %	Average* Hardness Change, Shore A
	Sasol Gasoline (FL-0229)	
Viton	2.4	-3.0
N219-7	11.8	-5.7
Buna 70	11.3	-3.3
Fluorosilicone	14.2	1.7
	Sasol Diesel (FL-0230)	
Viton	2.3	-4.0
N219-7	2.1	6.3
Buna 70	1.6	4.3
Fluorosilicone	5.6	2.3

* Average result for three test specimens.

c. Thermal Stability and Elastomer Compatibility Precision/Repeatibility

In anticipation of precision/repeatability criteria to be required for the AFQP, calculations have been made of the repeatability of elastomer swell and hardness data as reported in AFLRL Report No. 144[2] covering AFQP activities during FY1981. These are presented in Table 8.

An MDF* of 3.926 (4 degrees of freedom, 95 percent confidence level) was used, since all elastomer tests employed five replicate O-rings in the reservoir for each test. As can be seen, volume swell repeatability as measured per ASTM D471 was 3.2 percent, while hardness change repeatability per ASTM D2240 was 4.2 Shore A points.

To evaluate JFTOT thermal stability precision, a special series of ASTM D3241 tests (with the exception of a variable max tube temperature) were run on three distinctly different diesel fuels:

- Petroleum DF-2 AL-9979
- Sasol coal (DF-2) FL-0230-SP-F
- Paraho-II shale (DFM, AL-10150-SP-F)

Thermal stability and calculated repeatability results are presented in Table 9.

Note that repeatability calculations are for only the groups of five replicates at 275°C max tube temperature for each fuel so as to provide four degrees of freedom, the minimum required for ASTM repeatability (MDF = 3.926, 95 percent confidence level). The individual repeatability values for each category (Visual Code, spun and

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* MDF = 1.414 $t_{.95}$; MDF = 3.926 for all testing reported herein, since five replicate tests were used in all cases. Repeatability = 1.414 $t_{.95}s_r$. NOTE: MDF is called "limit multiplier," widely used in CRC/ASTM activities.

TABLE 8. CALCULATED REPEATABILITY — ELASTOMER SWELL AND HARDNESS (1)

Elastomer		Petro DF2	Coal MTG	Paraho DFM	50% Arom	10% Arom	Bicyclic	Nitrogen	Peroxide	Sulfur	0.1 TAN	Composite
Gum Rubber	V%(2)	3.4	2.9	2.6	4.7	0.9	3.3	2.7	7.3	1.4	2.5	2.8
	H(3)	3.3	6.0	3.3	4.8	6.6	0.0	5.1	0.5	5.1	0.0	3.5
Acrylonitrile/ Butadiene	V%	7.7	4.7	3.3	4.9	1.4	3.2	2.3	1.3	3.0	2.7	2.6
	H	1.8	5.3	1.8	2.2	6.5	7.3	4.5	3.5	8.3	4.5	3.5
Ethylene/ Propylene Rubber	V%	45.8	8.8	37.1	46.1	19.8	61.3	20.4	22.9	25.1	61.8	—
	H	7.6	5.0	8.1	1.8	6.0	6.2	8.1	10.8	5.1	7.1	—
Fluorocarbon	V%	1.8	1.3	2.2	8.4	1.6	3.7	0.7	1.1	2.4	7.1	—
	H	3.9	3.3	5.8	3.3	3.5	2.2	10.5	4.3	4.3	9.0	—
Acrylonitrile/ Butadiene	V%	1.2	8.8	2.4	2.8	6.1	3.2	0.5	3.2	1.5	2.0	—
	H	3.3	3.3	7.3	4.3	0.0	4.5	6.2	0.0	6.6	4.5	—

Grand Means (4):
Volume Swell = 3.2%
Hardness Change = 4.2 Points (Shore A)

(1) Modified JFTOT procedure (150°F sump, 2.5 hr)
(2) % volume swell (wet) per ASTM D 471
(3) Hardness change (wet - Shore A scale) per ASTM D2240
(4) Does not include ethylene/propylene rubber

TABLE 9.
JFTOT DATA FOR PETROLEUM, COAL, AND SHALE DIESEL FUELS

Test No.	Fuel Code	Fuel Type	Max Tube Temp, °C	Max Tube Deposit ASTM Vis Code	Max Tube Deposit TDR Spun	Max Tube Deposit TDR Spot	Filter Fouling, ΔP mm Hg	Filter Fouling, ΔP Min
T134	AL-9979	Petro DF2	245	0	3	7	0	150
T135	AL-9979	Petro DF2	245	0	2	5	0	150
T137	AL-9979	Petro DF2	245	1	5	7	0	150
T138	AL-9979	Petro DF2	245	0	3	7	0	150
T136	AL-9979	Petro DF2	262	0	5	7	0	150
T141	AL-9979	Petro DF2	262	1	3	6	0	150
T146	AL-9979	Petro DF2	275	1	3	6	0	150
T147	AL-9979	Petro DF2	275	0	4	5	0	150
T148	AL-9979	Petro DF2	275	1	3	5	0	150
T149	AL-9979	Petro DF2	275	2	6	12	0	150
T150	AL-9979	Petro DF2	275	2	6	10	0	150
T139	FL-0230-SP-F	Sasol DF2	275	3	30	37	0	150
T142	FL-0230-SP-F	Sasol DF2	275	3	36	42	0	150
T143	FL-0230-SP-F	Sasol DF2	275	3	31	35	0	150
T144	FL-0230-SP-F	Sasol DF2	275	3	25	31	0	150
T145	FL-0230-SP-F	Sasol DF2	275	3	21	31	0	150
T140	AL-10150-SP-F	Paraho DFM	275	1	10	14	0	150
T151	AL-10150-SP-F	Paraho DFM	275	1	6	13	0	150
T152	AL-10150-SP-F	Paraho DFM	275	0	10	15	0	150
T153	AL-10150-SP-F	Paraho DFM	275	1	4	6	0	150
T154	AL-10150-SP-F	Paraho DFM	275	0	8	12	0	150

Calculated repeatabilities (275°C only)		Vis Code	Spun	Spot	ΔP
AL-9979	Petro DF2	3	6	13	0
FL--0230-SP-F	Sasol diesel	0	23	18	0
AL-10150-SP-F	Paraho DFM	2	10	14	0

spot TDR, ΔP) while statistically proper, seem intuitively conservative -- likely due to the mere four degrees of freedom and consequent MDF of 3.926 which in effect defines the repeatability as quadruple the standard deviation for five replications. For example, the spun TDR mean for the petroleum DF-2 is 4.4 with s_r = 1.5 and range = 6 - 3 = 3, while the allowable difference between any two determinations (the definition of repeatability) is 5.95, rounded to 6 in Table 9.

Had a larger number of tests (or O-rings within a test), say 15 or 20, been employed, the repeatability would likely have been much lower simply due to the nature of the statistical calculation.

d. Diesel Fuel/Elastomers Effects Study

A special sequence of 30 TOFT tests were executed to identify fuel/elastomer effects for the three most comparable diesel fuels (one petroleum-derived, one shale-derived, and one coal-derived). A 3x4x5x2 factorial design was implemented wherein three fuels were crossed with four elastomer types using five O-rings of each type per test with replicate hardness and swell data taken independently by two experienced TOFT operators. Specifically, test conditions and materials were:

- Three test fuels: Petroleum Reference Fuel (AL-10115), Shale Paraho II DFM (AL-10150), and Coal Sasol II diesel fuel (FL-0230)
- Four elastomer materials (fluorocarbon (Viton), N-219, Buna N-70, and fluorosilicone)
- "Standard" TOFT conditions (66°C sump temperature, 260°C max tube temperature, otherwise standard ASTM D3241 test procedures for JFTOT)

Five O-rings were employed in each test (except control tests where no O-rings were used). Elastomer swell and hardness change were measured independently by the two technicians immediately after test; preheater tube Visual Code was also measured independently by these two technicians, while TDR measurements were taken independently by the two technicians plus two SwRI staff members for additional confirmation. The test schedule is shown in Table 10.

The data were averaged over operators and O-rings; this gave a single swell, hardness and TDR value each for a given test. Analysis of Variance was then conducted to identify any significant differences in swell, hardness, and TDR values which could be attributed to differences between fuels, elastomers or certain fuel-elastomer combinations. Raw elastomer data for swell are presented in Table B.1*, for elastomer hardness change in Table B.2*, and for thermal stability in Table B.3*. Analysis of Variance printouts together with tables of residuals are correspondingly presented in Tables B.4*,B.5* and B.6* for swell, hardness, and TDR, respectively. Corresponding bar-chart plots of swell, hardness, and TDR are given in Figures 4 through 6.

The Analysis of Variance showed several statistically significant inferences. In general, these were:

- For elastomer swell, there were significant elastomer and fuel effects with a slightly less significant fuel-elastomer interaction effect

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* Tables B.1- through B.6 are presented in Appendix B.

TABLE 10
TOFT TESTS
(All at 260°C tube, 66°C (150°F) sump)

Test No.	Fuel	Elastomer (5 O-rings/test)
1A	AL-10115 (Petroleum)	None
1B	" " "	None
2A	" " "	Viton(fluorocarbon)
2B	" " "	Viton(fluorocarbon)
3A	" " "	N-219
3B	" " "	N-219
4A	" " "	Buna N 70
4B	" " "	Buna N 70
5A	" " "	Fluorosilicone
5B	" " "	Fluorosilicone
6A	AL-10150 (Paraho II DFM Shale)	None
6B	" " "	None
7A	" " "	Viton(fluorocarbon)
7B	" " "	Viton(fluorocarbon)
8A	" " "	N-219
8B	" " "	N-219
9A	" " "	Buna N 70
9B	" " "	Buna N 70
10A	" " "	Fluorosilicone
10B	" " "	Fluorosilicone
11A	FL-0230 (Sasol II Diesel Coal)	None
11B	" " "	None
12A	" " "	Viton(fluorocarbon)
12B	" " "	Viton(fluorocarbon)
13A	" " "	N-219
13B	" " "	N-219
14A	" " "	Buna N 70
14B	" " "	Buna N 70
15A	" " "	Fluorosilicone
15B	" " "	Fluorosilicone

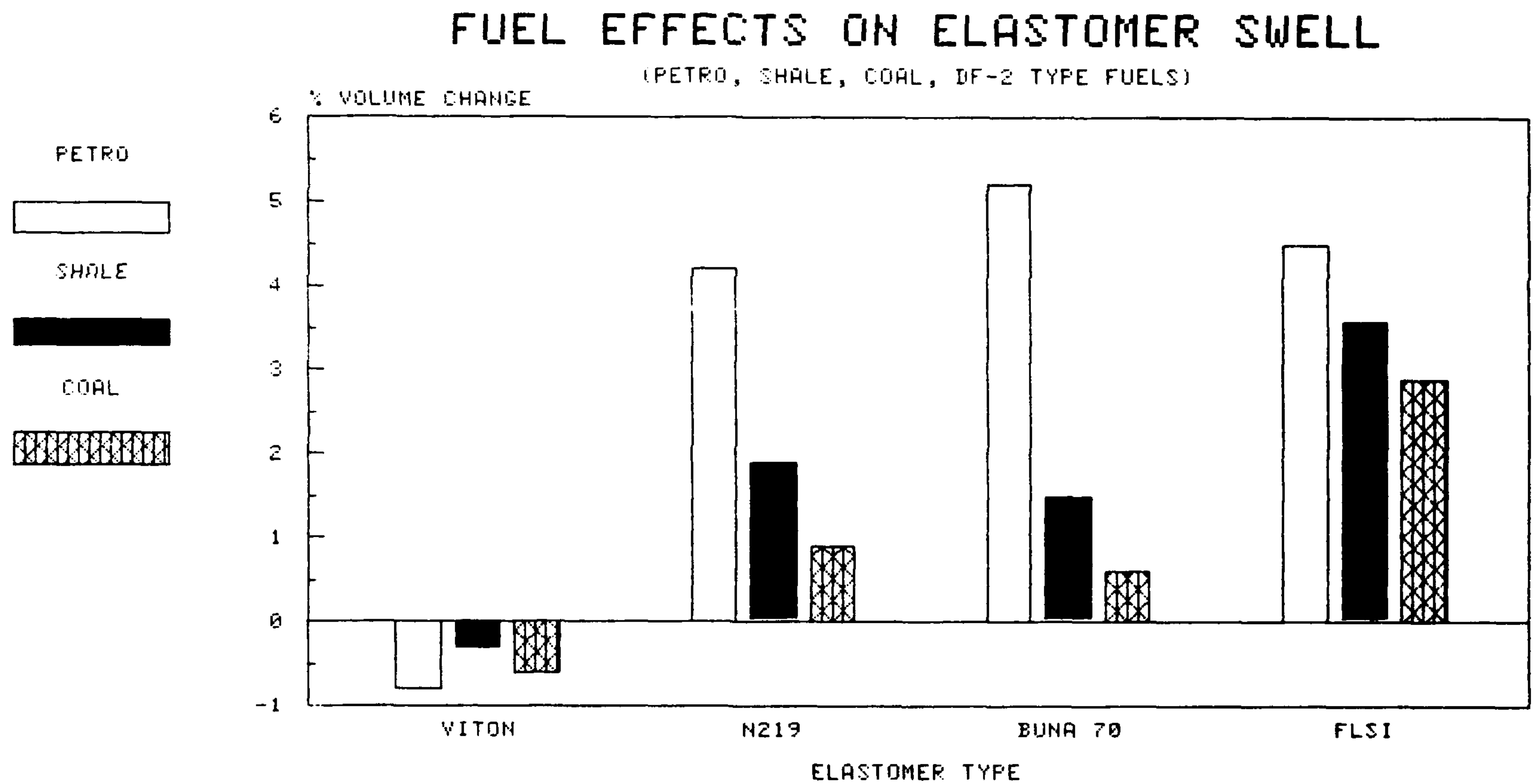


FIGURE 4. FUEL EFFECTS ON ELASTOMER SWELL

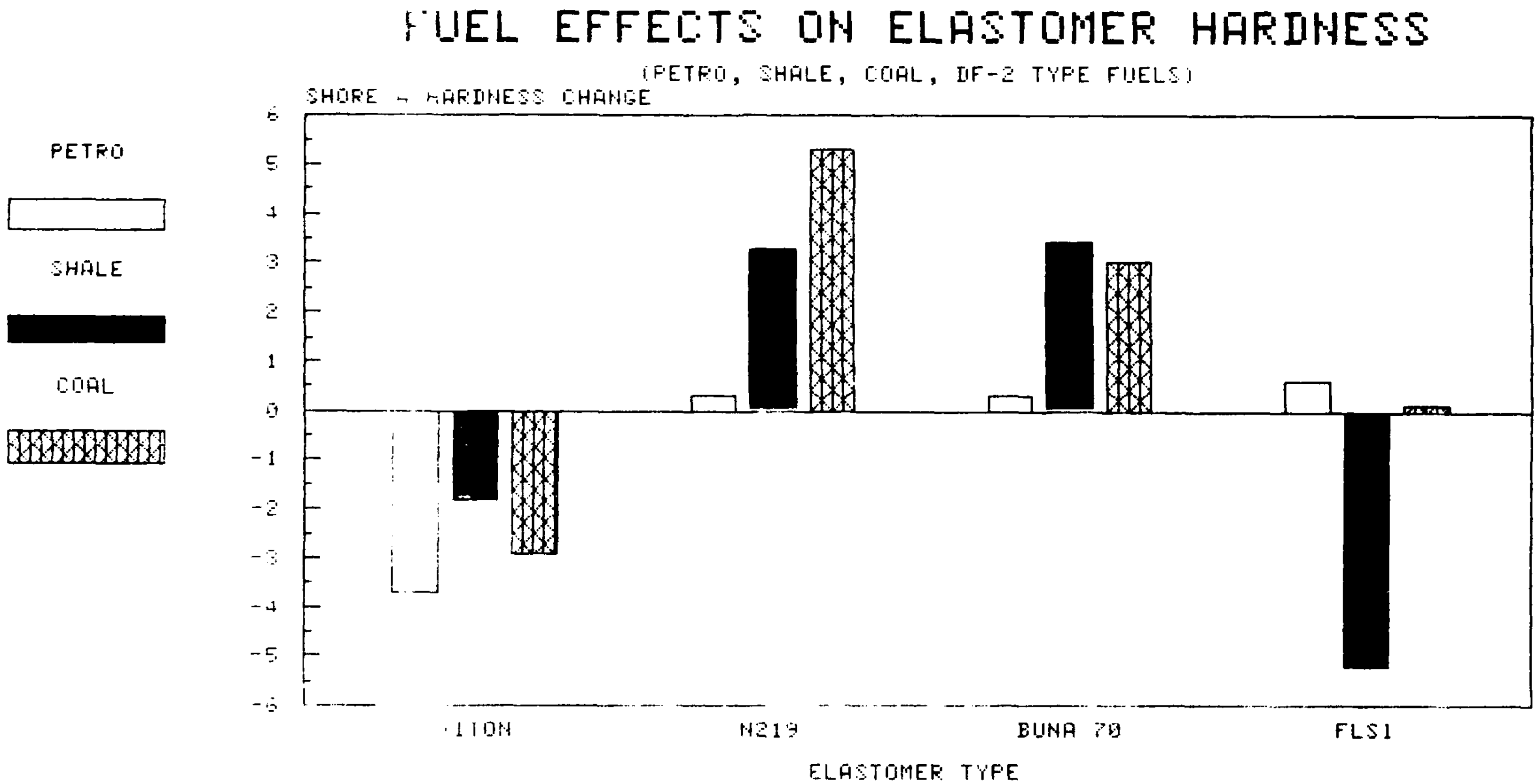


FIGURE 5. FUEL EFFECTS ON ELASTOMER HARDNESS

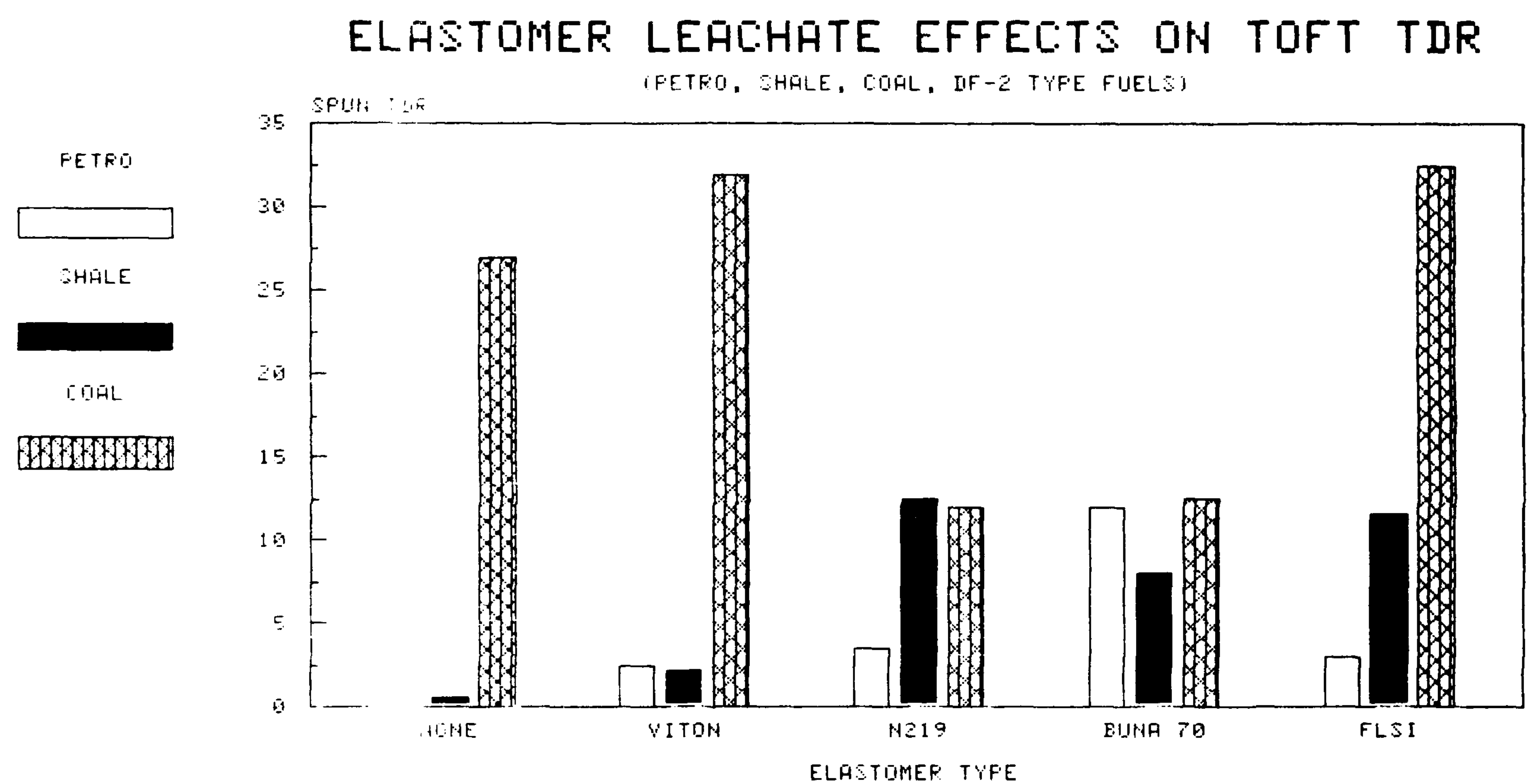


FIGURE 6. ELASTOMER LEACHATE EFFECT ON TOFT TDR

- For hardness change, there was a significant elastomer effect with a considerably less significant fuel and fuel-elastomer interaction effect
- For TDR, there were significant fuel and fuel-elastomer interaction effects

More specifically, inferences which can be derived from these data are:

- Thermal stability for the coal-derived (Sasol) diesel fuel as measured by spun TDR was poor as compared to the other two diesel fuels for the reference test (no elastomers) and for the fluorocarbon and fluorosilicone elastomers.
- The fluorocarbon elastomer showed no deleterious effects on thermal stability for the petroleum and shale derived fuels. This was equally true for the fluorosilicone elastomer.
- The acrylonitrile/butadiene elastomer tests (N219 and Buna N-70) showed somewhat different results for all three fuels. The N219 had essentially no effect on the petroleum DF-2 but apparently caused a significant increase in TDR for the normally stable shale fuel (Paraho II DFM). The Buna-70 apparently caused some increase in TDR for the petroleum DF-2 and slightly less for the Paraho-II DFM, but, in the opinion of the writer, neither of these materials appreciably affected thermal stability as measured by JFTOT spun TDR since readings only varied from 2.5 to 12.5.
- The single anomaly was for the two acrylonitrile/butadiene materials tested with the coal derived fuel, wherein a dramatic reduction in spun TDR (as compared to reference fluorocarbon and fluorosilicone data) was observed.

- Elastomer swell results were relatively consistent in that the fluorocarbon provided less than a 1% shrink for all three fuels (as expected) and a well-ordered "stairstep" fuel-to-fuel effect was noted for the other three elastomers. Swell for all three elastomers was greatest for the petroleum DF-2 followed by the shale and then the coal fuels. It is argumentative whether there is any difference between fuels for the fluorosilicone tests, but there are noticeable differences for the two acrylonitrile/butadiene materials with petroleum swell being far greater than for the other two fuels.
- Hardness data (differential Shore A, pre- and post-test) reflected a consistent similarity for the two acrylonitrile/butadiene materials with virtually no change in hardness for the petroleum tests and 3-5 points change for the shale and coal tests. The fluorocarbon tests reflected a softening for all three fuels of from 2 to 4 points, while the fluorosilicone tests showed essentially no change in hardness for the petroleum and coal fuels but a large (5 points) softening for the shale fuel. To confirm this last observation, tests were repeated and resulted in almost exact duplication of the original data. (These last two tests were not included in the Analysis of Variance).

Since numerous other measurement techniques (some ASTM methods, some new experimental techniques as in this program) frequently regard elastomer hardness changes to be insignificant unless they are greater than 10 Shore A points, a random selection of twenty new O-rings of each of the four elastomer types were subjected to Shore A hardness measurements (4 measurements at 90° on each O-ring). This four-elastomer/twenty-coupon/four-replicate sub-study was then subjected to the Analysis of Variance with the following overall results:

Elastomer	Degrees of Freedom	Analysis of Variance Results F-Ratio	Level of Significance
Acrylonitrile/ Butadiene (N-219)	19,60	26.72	.001
Acrylonitrile/ Butadiene (Buna N-70)	19,60	33.26	.001
Fluorocarbon (Viton)	19,60	2.30	not significant
Fluorosilicone (FLSI)	19,60	0.99	not significant

The next step will obviously be to set quality assurance limits for O-ring coupons by elastomer, these limits to be incorporated into the TOFT procedure/criteria for the AFQP.

2. Fuel Lubricity

a. General

The lubricating ability (lubricity) of fuels, both aeronautical and non-aeronautical, is becoming of increased concern for the future. This is a consequence of the extraordinary refining techniques, principally hydrotreatment, required for processing poor quality petroleum crudes and syncrudes. Such techniques serve to remove trace polar constitutents which normally impart some measure of lubricity to a fuel. Poor lubricity fuels may result in distress in vehicular fuel distribution systems, e.g., accelerated or severe wear in components such as fuel pumps, controls, and injectors.

b. Test Apparatus and Procedures

The bench test apparatus employed in this program for the measurement of fuel lubricity is known as the Ball-on-Cylinder Machine (BOCM). The device, shown in Figure 7, and detailed test techniques have been described previously.[2] Briefly, the apparatus consists of a fixed 0.5-inch diameter ball loaded against a 1.75-inch diameter rotating cylinder. The lower portion of the test cylinder is in contact with the test fuel. Air at a controlled relative humidity (10 percent) and temperature (25^{o} $\pm 1.5^{o}C$) is metered to the test chamber at a flow of 283 L/h (10 ft^3 /hr), passing over and through the test fuel. This airflow is maintained for a 15-minute pretreatment period and throughout the 30-minute test during which a 1000-gram load is applied to the ball. Test fluid sample volume is normally 0.025 L. Cylinder rotating speed is 56 cm/sec (240 rpm).

After test, an elliptical wear scar is observed on the test ball. The major and minor axes of the ellipse are measured microscopically and the mean of the two axes is reported as the wear scar diameter (WSD).

c. Lubricity Results

Criteria defining satisfactory or unsatisfactory fuel lubricity as measured by the BOCM are generally unavailable. Based on a limited number of operational incidents, the Navy[3] established tentative guidelines for JP-5 aircraft turbine fuels as follows:

Good	WSD $\leq$ 0.42 mm
Marginal 0.43 mm $\leq$	WSD $\leq$ 0.48 mm
Poor	WSD $\geq$ 0.49 mm

The applicability of these criteria in ranking other fuel types or for nonaeronautical engines has not been established.

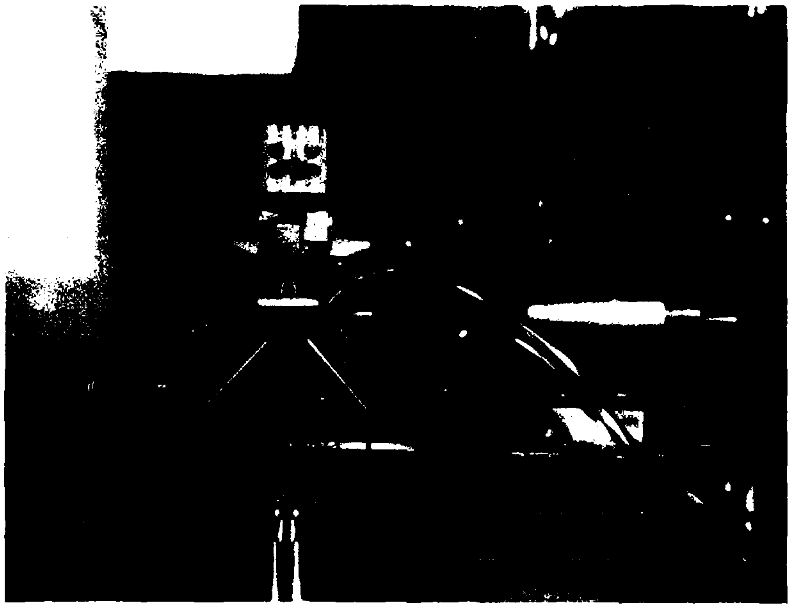


FIGURE 7. BALL-ON-CYLINDER MACHINE (BOCM)

Recent Navy-sponsored work (Contract No. N00140-80-C-2269), in progress, on aircraft turbine engine main fuel pumps indicates that the effect of poor lubricity fuel is highly equipment dependent. That is, some engine fuel pumps show negligible wear with fuel giving a BOCM value of 0.6 mm and higher. Component test studies, subsequently described herein, on ground vehicle fuel pumps present a similar finding.

Table 11 lists BOCM results for the six primary test fuels. As evidenced by the agreement between duplicate determinations on each fuel, test repeatability was very satisfactory. Prior work[2] has indicated that BOCM repeatability, as measured by standard deviation, is approximately ± eight percent of the mean wear scar diameter. The criterion for judging significant effects between test fuels or adjusted parameters is taken to be a WSD difference of plus or minus two standard deviations (16 percent).

The mean WSD data given in Table 11 show that all fuels except the Paraho-II DFM possess reasonable lubricity characteristics. The lowest (best lubricity) mean WSD was obtained with Cat 1-H. Applying the 16 percent significance criterion, this fuel is superior in lubricity to the shale BCF and coal BCF, and comparable to the SRC-II diesel blend and petroleum BCF.

The Paraho DFM yields a wear scar roughly twice that of the other fluids. The poor wear test performance of this fuel is attributed to the extensive refinery processing which was applied in the production of the fuel. It is noted that the Paraho sample is also identified by drum number in Table 11. Drum identification was necessitated by earlier findings[2] which showed a drum-to-drum variation in BOCM data, possibly due to trace container contamination. The mean WSD of 0.58 mm obtained in this study is one of the highest results among six drums sampled to date.

TABLE 11. LUBRICITY RESULTS FOR BASE FUELS

Fuel Code	Description		BOCM WSD, mm
AL-110115-F	Petro Cat 1-H		0.26
			0.27
		Mean	0.26
AL-10150-SP-F	Paraho-II DFM, drum 3		0.56
			0.60
		Mean	0.58
AL-10289-F	SRC-II, med cetane		0.31
			0.30
		Mean	0.30
AL-10286-F	Petro BCF		0.29
			0.29
		Mean	0.29
AL-10305-F	Shale BCF		0.36
			0.33
		Mean	0.34
AL-10306-F	Coal BCF		0.32
			0.32
		Mean	0.32

In Table 12, fuel lubricity results illustrate the effects of fuel clay treatment (CT) and TOFT induced deterioration on the six primary program test fuels. Clay treatment normally serves to reduce the lubricating ability of a fuel through adsorption of trace polar constituents which enhance lubricity. The treatment procedure used in this study employed an Attapulgus clay, 30/60 mesh, LVM (calcined) grade. Prior to use the clay was conditioned overnight at 232°C. The technique employed a volumetric clay/fuel ratio of 0.1 L/3.8 L and a fuel flow equivalent to a 10-minute residence time.

As seen in Table 12, significant increases in the wear scar occurred for all fluids after clay treatment except the two fuels containing coal-derived fractions. The relatively good lubricating capability of the latter two fuels is probably attributable to the presence of appreciable amounts of lubricity-improving compounds such as phenols and amines. One portion of the SRC-II diesel fuel, AL-10289-F, was subjected to a double-pass clay treatment, but no increase in the size of the WSD was observed after BOCM evaluation.

BOCM results are also given in Table 12 for used fuel samples generated by TOFT evaluation. The fuels were examined in the TOFT as received (neat) and following clay treatment. Clay treatment was not performed subsequent to the TOFT test. WSD data for this series of samples show a marked improvement in fuel lubricity for most of those fluids which gave large WSD's prior to the TOFT test. Such samples were mostly the clay-treated fuels, although the clay-treated Cat 1-H was an exception. Improved fuel lubricity subsequent to TOFT evaluation is presumably associated with the formation of gums and their fuel degradation products which can augment lubricity.

TABLE 12. EFFECTS OF CLAY TREATMENT AND TOFT INDUCED DETERIORATION ON FUEL LUBRICITY

Fuel Code	Fuel Type	BOCM WSD,* mm			
		Pre-TOFT		Post-TOFT	
		Neat	CT	Neat	CT
AL-10115-F	Petro Cat I-H	0.26	0.50	0.29	0.46
AL-10150-SP-F	Paraho-II DFM, drum 3	0.58	0.72	0.46	0.45
AL-10289-F	SRC-II, *med cetane*	0.30	0.23	0.32	0.26
AL-10286-F	Petro BCF	0.29	0.42	0.29	0.33
AL-10305-F	Shale BCF	0.34	0.49	0.34	0.39
AL-10306-F	Coal BCF	0.32	0.28	0.34	0.30

* Average of duplicate determinations.

Table 13 lists lubricity data for used TOFT fuel samples with and without selected elastomers. Underscored values identify significant elastomer effects based on the 16 percent criterion. Although the effect was negligible in some instances, the presence of the elastomer consistently showed a lubricity improvement for all six test fuels. The effect was most pronounced for the Paraho diesel fuel, probably emphasized by the fact that the fuel exhibited the highest WSD without an elastomer present. Based on the number of underscored values, the two petroleum base fuels showed the fewest cases (one) of significant elastomer effects on lubricity. The effect of individual elastomers on lubricity was variable among the six fuels. However, it is noted that Viton produced a marked improvement for all fuels.

Duplicate BOCM determinations on each of the Sasol coal-derived products gave the following values:

	WSD, mm
Sasol gasoline	0.30, 0.29
Sasol diesel	0.36, 0.33

These results would be considered to be indicative of good lubricity fuels. Wear scar values for the gasoline are particularly low in view of the fact that the standard 1000-g load was used in BOCM testing. Petroleum gasolines would normally be evaluated at a 100- or 200-g load to avoid wear specimen scuffing.

BOCM lubricity evaluations in this study were also performed for pure and mixture blends of isooctane and toluene to investigate the lubricating characteristics of paraffinic/aromatic blends. Wear data were obtained for the neat fluid samples as blended, and for post-test samples taken from TOFT tests with and without elastomers present. All BOCM determinations with these fluids were conducted at a reduced load of 100 g.

TABLE 13. LUBRICITY RESULTS FOR TOFT ELASTOMER TEST FUELS

	BOCM WSD*, mm					
TOFT Elastomer	Petro Cat 1-H AL-10115-F	Paraho-II DFM AL-10150-SP-F	SRC-II, Med Cetane AL-10289-F	Petro BCF AL-10286-F	Shale BCF AL-10305-F	Coal BCF AL-10306-F
None	0.29	0.46	0.32	0.29	0.34	0.34
Fluorosilicone	0.27	0.32	0.27	0.28	0.29	0.27
Buna N219-7	0.28	0.26	0.26	0.24	0.27	0.29
Buna N 70	0.24	0.38	0.25	0.26	0.25	0.27
Viton	0.23	0.28	0.24	0.22	0.28	0.24

* Average of duplicate determinations; underscored values identify significant elastomer effects.

Table 14 presents the BOCM test results for the series. Comparison of the as-- blended fluid values reveals a significant reduction in the wear scar for all blends containing some percentage of toluene. Wear for the blends was appreciably less than that for toluene alone, indicating a synergistic effect between the paraffin and aromatic components. A similar effect for such blends was observed by Appeldoorn and Tao.[5] The high WSD of 0.69 mm for isooctane compares favorably with prior values[2] (0.67 mm average) for the fluid.

An unusual effect was also demonstrated by the isooctane/toluene blends when comparing the neat fuel data with the post-TOFT runs without an elastomer present. The pure compounds showed a significant reduction in WSD after TOFT exposure, which is the expected result as a consequence of fluid deterioration (gum formation) in the high-temperature TOFT environment. The fluid blends, unexpectedly, indicated a statistically significant increase in WSD for all three mixtures.

BOCM data in Table 14 for the used isooctane/toluene samples from TOFT tests with elastomers present likewise exhibited an unusual trend for wear. Relative to wear results for post-TOFT samples and no elastomer present, data for the test samples with Viton and, with one exception, fluorosilicone indicated comparable or slightly improved lubricity. The exception for fluorosilicone occurred with the 60/40 mixture. In contrast, the two Buna elastomers N219-7 and N70, showed a deleterious effect on wear, especially at the higher aromatic concentrations.

3. Metal Corrosion

a. General

Isolated instances of corrosion problems with shale fuel have been reported. While such cases have been relatively rare and causes unidentified, there is sufficient

TABLE 14. LUBRICITY RESULTS FOR ISOOCTANE/TOLUENE BLENDS

Vol Percent			BOCM
Isooctane	Toluene	TOFT Elastomer	WSD*, mm
100	0	None, as blended	0.69
		None, post-TOFT	0.23
		Viton	0.20
		N219-7	0.27
		Buna N 70	0.28
		Fluorosilicone	0.21
70	30	None, as blended	0.17
		None, post-TOFT	0.26
		Viton	0.19
		N219-7	0.31
		Buna N 70	0.18
		Fluorosilicone	0.28
60	40	None, as blended	0.23
		None, post-TOFT	0.28
		Viton	0.31
		N219-7	0.46
		Buna N 70	0.40
		Fluorosilicone	0.36
50	50	None, as blended	0.21
		None, post-TOFT	0.31
		Viton	0.22
		N219-7	0.40
		Buna N 70	0.39
		Fluorosilicone	0.29
0	100	None, as blended	0.30
		None, post-TOFT	0.22

* Average values for two or more determinations; all runs performed with 100-g load.

concern to warrant development of a simple, inexpensive test to monitor the corrosion tendency of new fuels toward typical fuel system metals. In prior work(2) a corrosion test cell containing several metal coupons was incorporated in the fuel flow system of the TOFT apparatus. Current studies utilized the same test cell but, to remove the complexity involved with the TOFT, a static fuel condition was used with the cell separated from the TOFT.

b. Test Apparatus and Procedures

Figure 8 illustrates the corrosion test cell with the metal specimens being inserted. The coupons are 3/4-inch by 1/4-inch washers mounted on a glass rod and separated by 1/4-inch glass spacers. Metal types under investigation include commercial terneplate, QQ-A-250/4 aluminum, CDA 937 bronze, QQ-I-652 cast iron, and QQ-C-576 copper (electrolytic).

With the static test procedure, fuel sample temperature is controlled at $95^\circ \pm 1^\circ$ C ($230^\circ \pm 2^\circ$ F) by means of low-watt-density band heaters encircling the test cell. Test duration is 168 hr $\pm$ 15 minutes. The test chamber is sealed and fuel vapor pressure at test temperature is permitted to accumulate, but the cell is not pressurized prior to the test.

c. Test Results

In the initial stages of this effort, consideration was given to the influence of dissolved water on fuel corrosivity. It was decided that water content should be included as a corrosion test parameter since fuel-water contact exists in virtually every aspect of fuel storage, including vehicular. As a consequence, fuel water content was monitored by Karl Fischer titration (ASTM Method D1744).

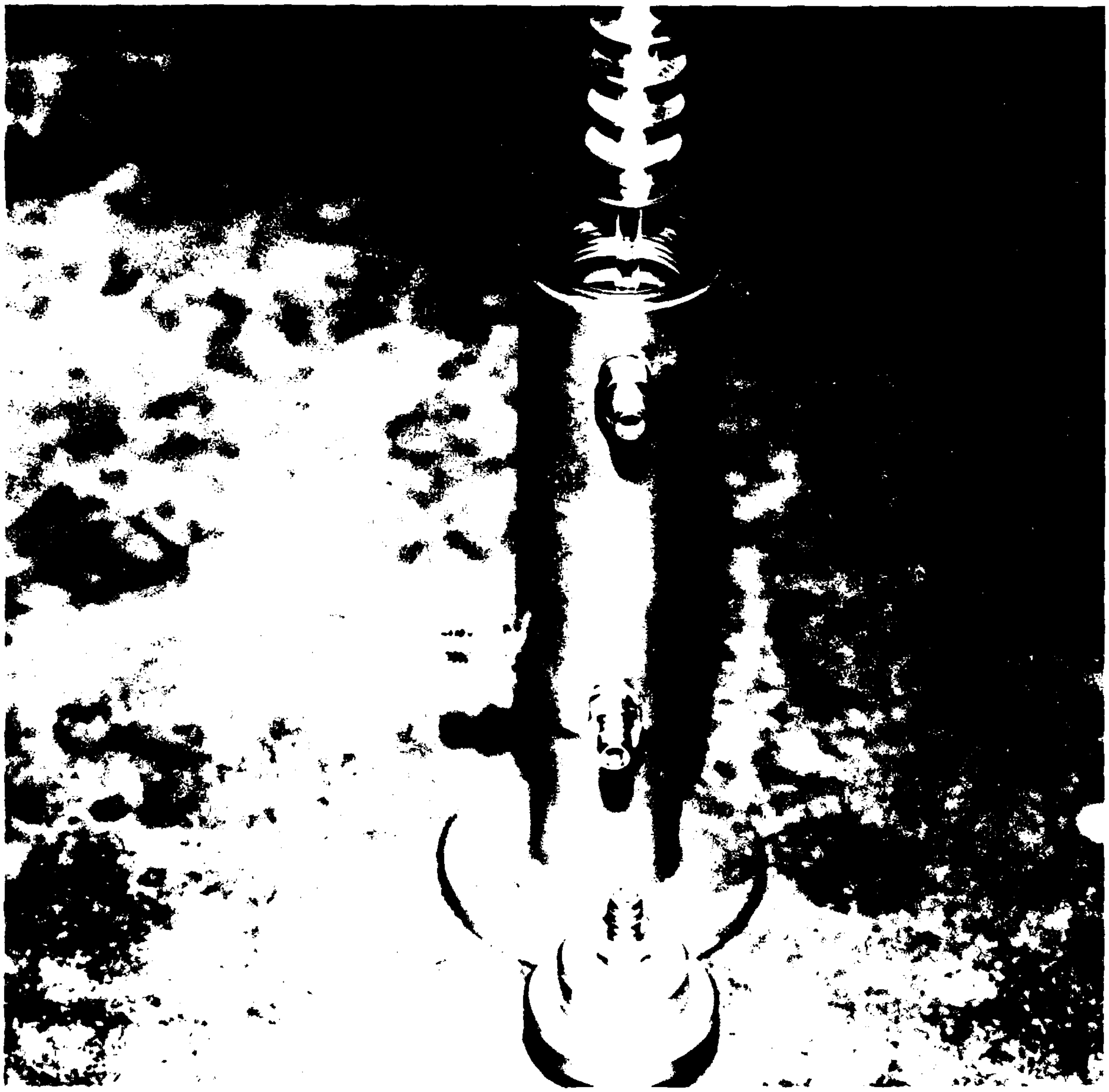


FIGURE 8. METAL CORROSION TEST CELL

Static water saturation of fuel samples was effected by storing fuel aliquots over water (deionized) in amber glass containers at a temperature of 23° ±1°C. Two pure hydrocarbons, toluene and isooctane (2,2,4-trimethylpentane), were included in the saturation study for comparison with handbook values to obtain some indication of the overall accuracy of procedures. Table 15 lists the data generated for the samples. The results indicate fluid saturation within 48 hours. In fact, values for isooctane show equilibrium occurred in 24 hours. Results for the pure materials show good agreement with data contained in the API Technical Data Handbook. This reference cites a water saturation value of approximately 88 ppm for isooctane and 470 ppm for toluene. The latter result is somewhat lower than values given in Table 15, but this may simply be due to some error in using the nomograph technique in the handbook. Alternately, within the region investigated, toluene shows considerable sensitivity to the saturation temperature. A range of ± 1°C is equivalent to a change of ± 15 ppm water. Thus, very precise sample temperature control would be required for accurate saturation data.

Two anomalous findings are shown by the Table 15 data -- the excessively high initial water content for the SRC-II diesel fuel and the very low saturation value for the Paraho-II DFM. A value of almost 0.2 wt percent for SRC-II is well above saturation for any type hydrocarbon. Although not readily apparent by visual examination, it was originally conjectured that the fuel must contain some emulsified water. In an effort to verify the existence of free water, or possibly the presence of fuel constituents causing false titers due to interference with the Karl Fischer reagent, some additional evaluations were performed. A sample of the SRC-II diesel fuel was available which had been subjected to a two-pass clay treatment. Analysis of a portion of the sample gave a water content of 260 ppm, indicating that the clay had

TABLE 15. WATER SATURATION RESULTS

Fluid	Water Content, ppm at 23°C					
	Initial	16 hours	24 hours	48 hours	72 hours	96 hours
Petro Cat 1-H AL-10115-F	154, 164	---	---	188, 193	197, 200	195, 190
Paraho-II DFM AL-10150	29, 33	54, 58	---	70, 75	68, 73	---
SRC-II, Med Cetane AL-10289	1850, 1930	1944	---	---	---	---
Petro BCF AL-10286	45, 53	---	---	---	130, 138	---
Shale BCF AL-10305	64, 60	---	---	---	122, 130	---
Coal BCF AL-10306	51, 65	---	---	---	120,113	---
Isooctane	67, 62	---	91, 80	83	---	---
Toluene	191, 179	---	---	---	522, 523	527, 520

absorbed a significant amount of water (or interfering substances). An aliquot of the clay-treated sample was then stored over water to determine its saturation value. Within 72 hours the moisture content of the fuel had risen to 1700 ppm.

Thus, it appears that the true saturation value of the fuel is near 0.2 wt percent and Karl Fischer interferants are negligible. This very high saturation value, relative to hydrocarbons, may be attributed to heteroorganics in the fuel. It is understood, for example, that SRC-II contains some phenols. Such compounds would be expected to absorb considerable water.

No explanation for the unusually low water saturation value for the Paraho-II DFM is currently available. Averaging the four determinations for Paraho-II at 48 and 72 hours (Table 15) yields a mean saturation value of 72 ppm for the fuel. This result is quite low for a fluid containing 30 vol percent aromatics. It is low even for a long chain normal paraffin which is the hydrocarbon type exhibiting the lowest water saturation values.

Corrosion data for the three diesel fuels are presented in Table 16. It was planned to evaluate corrosive tendency at moisture levels of as-received and saturated. In two instances, Cat 1-H and SRC-II, the as-received water content was close to the saturation value. Therefore portions of these two fuels were percolated through absorbent cotton to achieve a reduced moisture content.

As indicated in Table 16, only copper and bronze showed any appreciable attack. Results for the SRC-II fuel were consistent. The fuel caused a significant (>0.2 mg/cm^2 is a tentative criterion) weight loss for copper only, and the degree of corrosion was unaffected by moisture content.

TABLE 16. STATIC CORROSION TEST RESULTS FOR DIESEL FUELS
(168 hr; 95°C)

	Specimen Weight Loss, mg/cm²											
	Petroleum Cat 1-H					Paraho-II DFM				SRC-II Med Cetane		
Metal[a]	1	2	3	4	5	1	2	3	4	1	2	3
Copper	0.3	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.7	0.6	0.7
Bronze	0.0	0.5	0.4	0.0	0.7	0.0	0.0	0.7	0.1	0.1	0.1	0.1
Water content, % of sat'n	41	82[b]	82[b]	100	100	43[b]	43[b]	100	100	9	97[b]	100

(a) Negligible corrosion of cast iron, aluminum, and terneplate.
(b) Fuel water content as received.

The performance of the other two diesel fuels is obscured by the apparent lack of repeatability for duplicate determinations with the water-saturated samples. The dried (41 percent of saturation) Cat 1-H showed some attack of copper, but not bronze. The moist fuel samples produced a significant weight loss for bronze except for the number 4 determination. Paraho-II DFM indicated no appreciable corrosion except for the number 3 run which exhibited attack of bronze.

Corrosion test data for the three broadcut fuels are given in Table 17. Only the petroleum product caused appreciable metal attack. This occurred with bronze and the lower moisture content sample.

TABLE 17. STATIC CORROSION TEST RESULTS FOR BROADCUT FUELS (168 hr; 95°C)

	Specimen Weight Loss, mg/cm²					
	Petro BCF		Shale BCF		Coal BCF	
Metal[a]	1	2	1	2	1	2
Copper	0.0	0.0	0.1	0.0	0.0	0.0
Bronze	0.4	0.0	0.0	0.0	0.1	0.0
Water content, % of sat'n	37[b]	100	49[b]	100	50[b]	100

(a) Negligible corrosion of cast iron, aluminum, and terneplate.
(b) Fuel water content as received.

Results to this point indicated that appreciable metal corrosion was limited to copper and bronze, but the effect of fuel moisture content was obscured by the poor repeatability of metal weight loss data. In an attempt to determine the possibility of a nonuniform temperature distribution in the test cells, two determinations were performed in which only bronze and copper specimens were used in alternating positions on the glass rod. The following data were obtained in these tests:

	Wt Change, mg/cm^2	
	1	2
Bz (top)	-0.2	0.0
Cu	0.0	-0.1
Bz	-0.1	0.0
Cu	0.0	-0.1
Bz	-0.2	+0.1
Cu (bottom)	0.0	-0.1

In run 1, slight but reasonably consistent attack of the bronze coupons occurred. A similar performance was shown in run 2, but for copper.

A review of prior data indicated the same phenomenon --- significant copper <u>or</u> bronze corrosion had been observed but never copper <u>and</u> bronze in the same run. This suggested a possible interactive effect between the two metals. An additional factor believed to be contributing to poor test repeatability was the nature of the corrosion process. Microscopic examination of specimens showed that the most prevalent metal attack was crevice type corrosion occurring in the contact area between the specimens and the glass spacers. Thus, any imperfections in the spacer surfaces would affect the degree of corrosion. This could be minimized to some extent by hand lapping the spacer ends in subsequent testing. However, no corrective measures could be taken if a similar corrosion process were occurring due to random contact between the inside diameter of the washer and the glass mounting rod.

In order to avoid any interactive effect on corrosion between copper and bronze, additional experiments were performed using only copper or bronze specimens in the test cell. Four such determinations gave the following results:

Test Cell Position	Weight Change, mg/cm^2 Copper 1	Copper 2	Bronze 1	Bronze 2
1 (top)	-0.5	-0.2	-0.2	0.0
2	-0.5	-0.2	-0.2	-0.1
3	-0.4	-0.2	-0.2	0.0
4	-0.4	-0.2	-0.2	+0.1
5	-0.4	-0.2	-0.2	0.0
6 (bottom)	-0.4	-0.2	-0.2	-0.1

The initial determination on each metal indicated consistent metal losses and no significant effect for specimen position within the test cell. For both metal types, the repeat test showed noticeably less severe corrosion.

In spite of every effort to maintain good laboratory practice in the conduct of the corrosion test, it would appear that the procedure is only marginally repeatable. However, with present circumstances whereby copper has been the most susceptible to attack, the standard copper strip corrosion test (ASTM D130) could serve as the initial AFQP screening tool. The static test procedure used in this study would be employed to identify unusual fuel corrosion tendencies toward other metal types. The method would have particular application to newer fuel types such as coal-derived or alcohol-containing fuels.

D. Component Testing

1. General

A major program effort was devoted to the construction and development of a Component Endurance Test Facility (CETF), and its utilization in the evaluation of engine fuel systems operating with alternative/future fuels. The objectives of this investigation were two-fold---to identify these vehicular fuel systems displaying any sensitivity to fuel property changes, and to confirm or deny the applicability of the

BOCM as an appropriate tool for the measurement or control of fuel lubricity. Inasmuch as fuel combustion was not a part of the study, the two primary areas of interest were fuel and materials compatibility of elastomers and filter elements, and the performance of pumps and other metallic elements in relative motion on low lubricity fuels.

The selection of Army equipment fuel systems to be evaluated was based on the following ranking criteria:

- Materiel population
- Mission criticality
- Suspected or demonstrated fuel sensitivity

On the basis of these criteria, fuel systems and/or fuel injector pumps for the following diesel engine models were selected for component endurance testing: Continental AVDS 1790, Detroit Diesel 6V-53T, Cummins NHC 250, Continental LDT 465-1C, and the General Motors 6.2 L diesel engine. The AVDS 1790 powers the Army's M48 and M60 tanks, the M728 combat engineer vehicle, and the M88 recovery vehicle. The 6V-53T, NHC 250, and LDT 465 diesel engines in combination power some thirty-five combat or tactical type vehicles. The GM 6.2 L engine is that found on the newly procured Commercial Utility Cargo Vehicle (CUCV). The CUCV is a derivation of the Chevrolet Blazer and approximately 53,000 units are being acquired for Army inventory.

The various elements of the CETF will be described subsequently in connection with the AVDS 1790 fuel system which was the first component type evaluated with the CETF.

2. Test Apparatus and Conditions

a. AVDS 1790 Fuel System

Two 50-horsepower, variable speed drive stands were installed, and instrumentation and control systems adapted for the AVDS 1790 fuel system. Figure 9 illustrates the control panel for the two stands, while Figure 10, presents an overall view of the facility with the injector metering pumps and associated delivery lines in place. Fuel lines leading from the metering pump head terminate at the injectors, a row of six each mounted on either side of the drive stand. The injectors discharge into the circular manifold which is plumbed so that injector fuel delivery occurs beneath the fuel level within the manifold. The two large cylinders shown at the right in Figure 10 house clay-filter elements for control of the level of fuel lubricity.

The opposite-side view for one test stand seen in Figure 11 shows the 30-gallon fuel tank in the foreground. The gas cylinder at right provides for nitrogen blanketing of the fuel tank. Figure 12 is a closeup view of one metering pump with the fuel delivery lines removed. The smaller tubing lines shown in this photograph are associated with delivery and removal of lubricating oil to the pump drive mechanism. The larger line at upper right is the fuel inlet which enters the pump through a filter integral to the metering pump.

A flow schematic of the pump test loop is shown in Figure 13. The test fuel is pumped from the tank by means of a vane type boost pump which is an integral component of the AVDS 1790 fuel system. Fuel inlet temperature control is provided by a heat exchanger. A portion of the fuel delivered to the injection pump bypasses within the pump and returns to the tank via the overflow line. Similarly, some percentage of the fuel fed to the injectors normally serves as a coolant for the injectors and returns to the fuel tank via a bleed line. Fuel flow through the clay

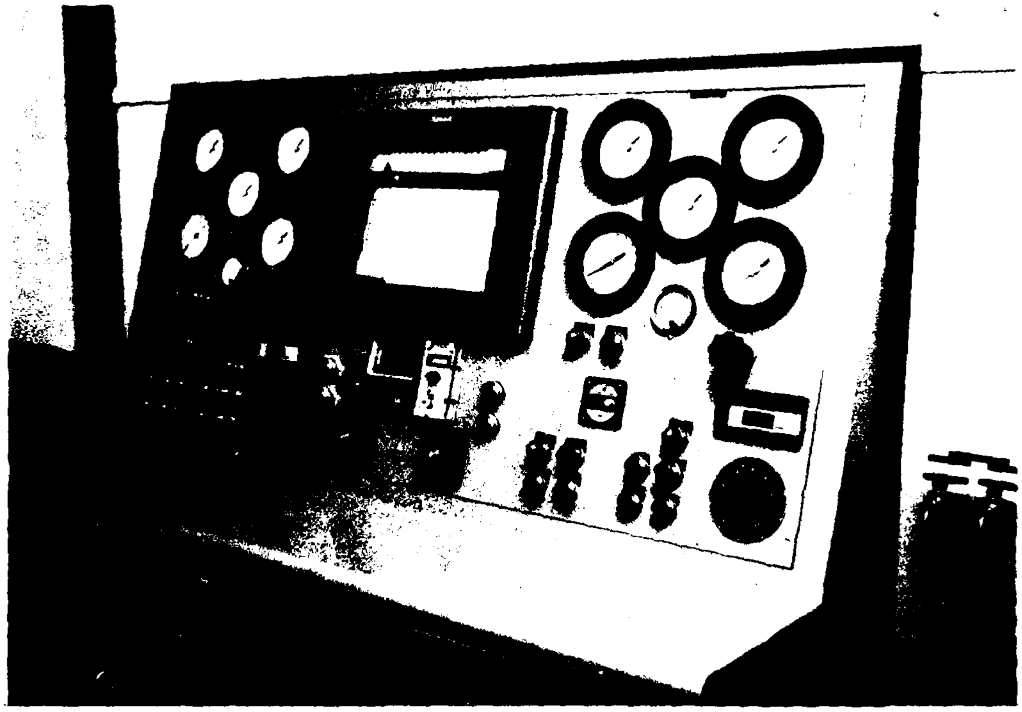


FIGURE 9. PUMP LOOP CONTROL PANEL

FIGURE 10. AVDS 1790 FUEL SYSTEM TEST RIGS

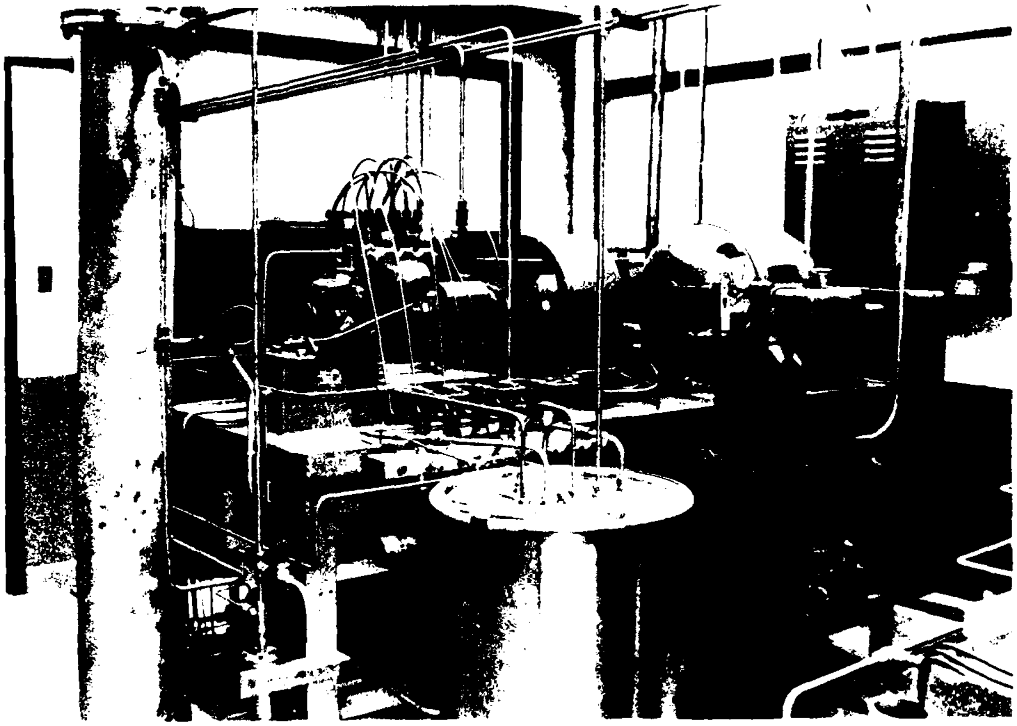


FIGURE 11. TEST RIG VIEW OF FUEL TANK

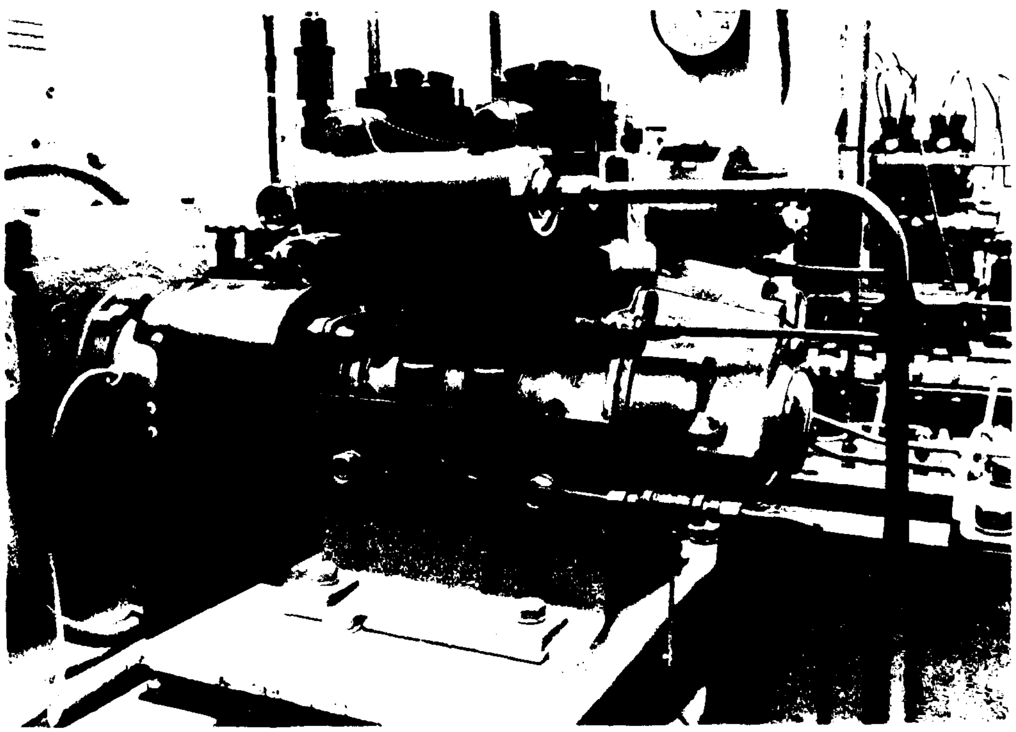


FIGURE 12. CLOSEUP VIEW OF AVDS 1790 INJECTOR PUMP

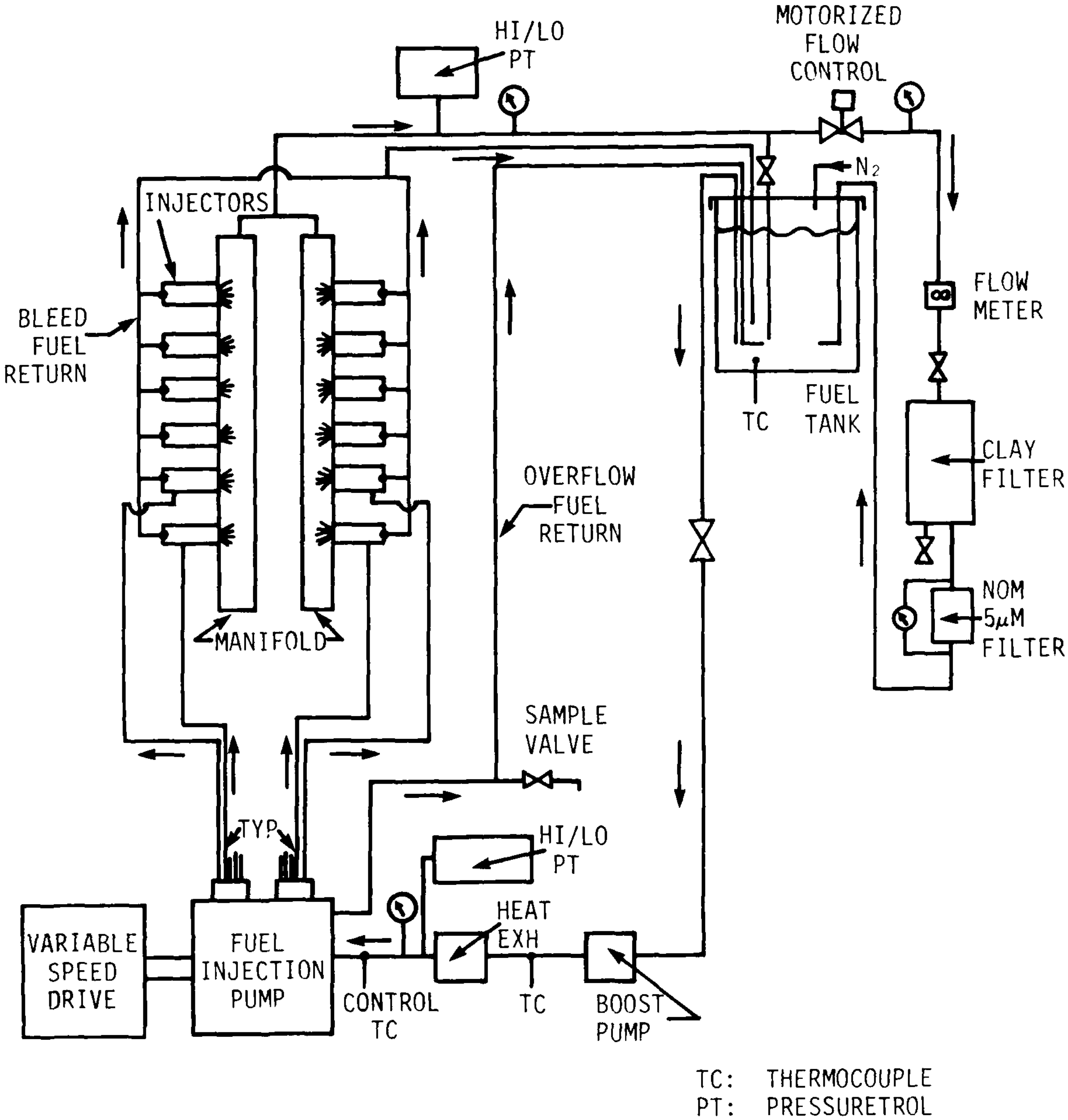


FIGURE 13. FLOW SCHEMATIC FOR AVDS 1790 FUEL PUMP TEST LOOP

filter is controlled by a motor-driven needle valve. A turbine flow meter in the line provides a signal to a calibrated digital readout at the operator's control panel. Downstream of the clay filter, a nominal 5 μm cleanup filter is provided to trap any migrating particulates. For safety purposes, all pump loop control operations, including fuel sampling, can be performed at the operator's console exterior to the test cell.

Except for those units integral to the AVDS 1790 system, the boost and injection pumps and the injectors, all metallic pump loop items in contact with the test fuel are fabricated of stainless steel. This approach in construction of the facility was taken in order to minimize any catalytic effect of materials on test fuel deterioration. Nitrogen blanketing of the system likewise serves to obviate oxidative degradation of the test fuel.

The two AVDS 1790 systems used in the endurance tests were provided on loan by Army maintenance units at Ft. Hood, Texas. The systems were new but had undergone calibration and performance characterization per TM-2910-212-34 by Ft. Hood personnel to verify the integrity of the pumps and injectors.

While all test facility parameters were monitored throughout a run, only three were controlled during test--injection pump shaft speed, inlet fuel temperature, and fuel flow through the clay filter. Pump speed was set at 2000 rpm, just under the governed speed of 2400 rpm. Inlet fuel temperature to the injection pump was controlled at 120°F. Ft. Hood personnel advised this fuel temperature is near the maximum encountered in service. Fuel flow rate through the clay filter was dictated by changes in fuel lubricity throughout a test. Lubricity was monitored by the Ball-on-Cylinder Machine at specified intervals, and flow through the clay filter adjusted

accordingly. The objective was to maintain a fixed fuel lubricity level, as measured by the BOCM, from test start to finish. With no flow through the clay filter, lubricity would improve with time as a consequence of fuel deterioration and the formation of lubricity enhancing constituents. This proved to be true for all pumps tested.

b. 6V-53T Injector Pump

Fuel system component evaluation for the 6V-53T engine was limited to the main fuel pump. Because of its relatively small size and low output, the CETF was not utilized for pump operation. Two bench-top test setups were employed for parallel testing. Each pump drive shaft was directly coupled to a constant speed, 1½ horsepower drive motor. Continuous pump operation was maintained with inlet fuel temperature controlled at 85°-90°F and pump outlet pressure set at 72 psig during test. At these conditions, selected on the advice of Ft. Hood maintenance, fuel flow rate was 4.3 L/min.

c. NHC 250 Injector Pump

The CETF and general procedures described for the AVDS 1790 pump were also used in the evaluation of the NHC 250 unit. One test rig included a clay-filter column in the fuel loop to maintain lubricity at a consistently poor level; no clay filter was used in the second rig, the test fuel being permitted to degrade, i.e., improve in lubricity, for comparison. With the guidance of Ft. Hood personnel, the following test conditions were controlled at indicated values:

- Pump speed 2000 rpm
- Outlet pressure 175 psig
- Inlet fuel temperature 120°F

At these conditions, nominal fuel flow rate was 3.8 L/min.

Both NHC 250 test pumps were obtained on consignment from Ft. Hood where they had been subjected to the evaluation sequence specified in Test and Calibrations, Fuel Injection Systems, Supplement I-- an unnumbered document issued by the New Equipment Training Branch, U.S. Army Tank-Automotive Command.

d. <u>LDT 465-1C Injectors and Pump</u>

The LDT 465 pump with associated injectors (six each) was investigated on a Unitest Universal Test Machine Model No. 14500EX, an apparatus designed for testing American Bosch equipment to production specification. A 7.5-horsepower motor coupled to the injection pump drives the unit at a constant 1200 rpm. Volumetric injection output is measured periodically for both injector and bypass fuel flow.

e. <u>CUCV Injector Pump</u>

This device was evaluated using the CETF, employing conditions for rated operation of the pump as recommended by the pump manufacturer, Stanadyne, Inc. The pump was run with injectors attached to the fuel lines. Outlet fuel pressure was maintained by the eight injectors which discharged into a small auxiliary sumps. An overall view of the mounted pump and associated fuel lines connected to the sump is shown in Figure 14. A close-up photograph of the unit is given in Figure 15. The electrical lines seen in the figure provide power to the fuel on-off solenoid. The tube leading from the top of the pump housing is a bleed-fuel return line to the tank. This line contains a thermocouple tee near the pump body which serves as the fuel temperature control location.

Test conditions suggested by the manufacturer were as follows:

Pump speed	2000 rpm
Outlet fuel pressure	4500 psig
Bleed fuel temperature	125^oF

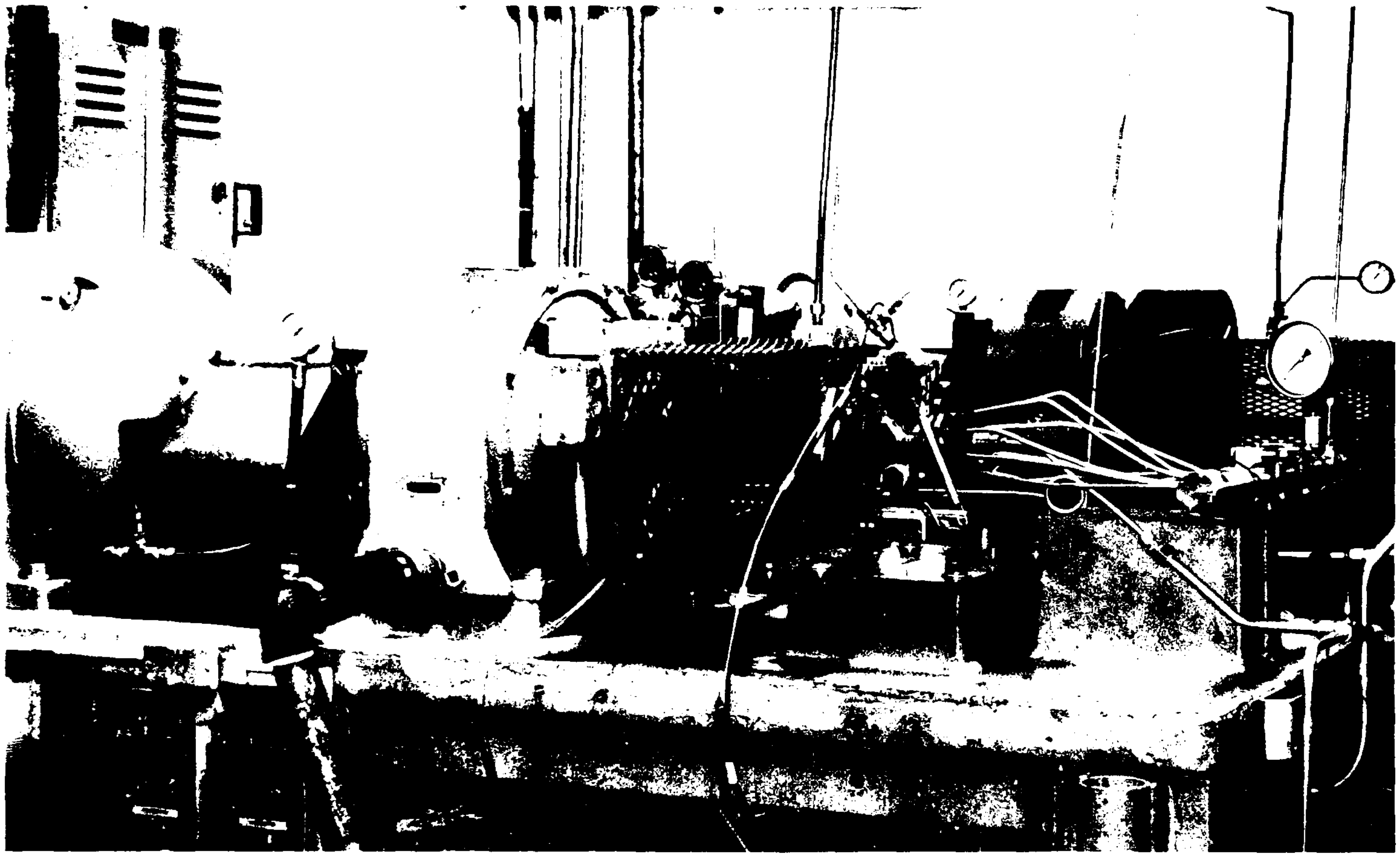
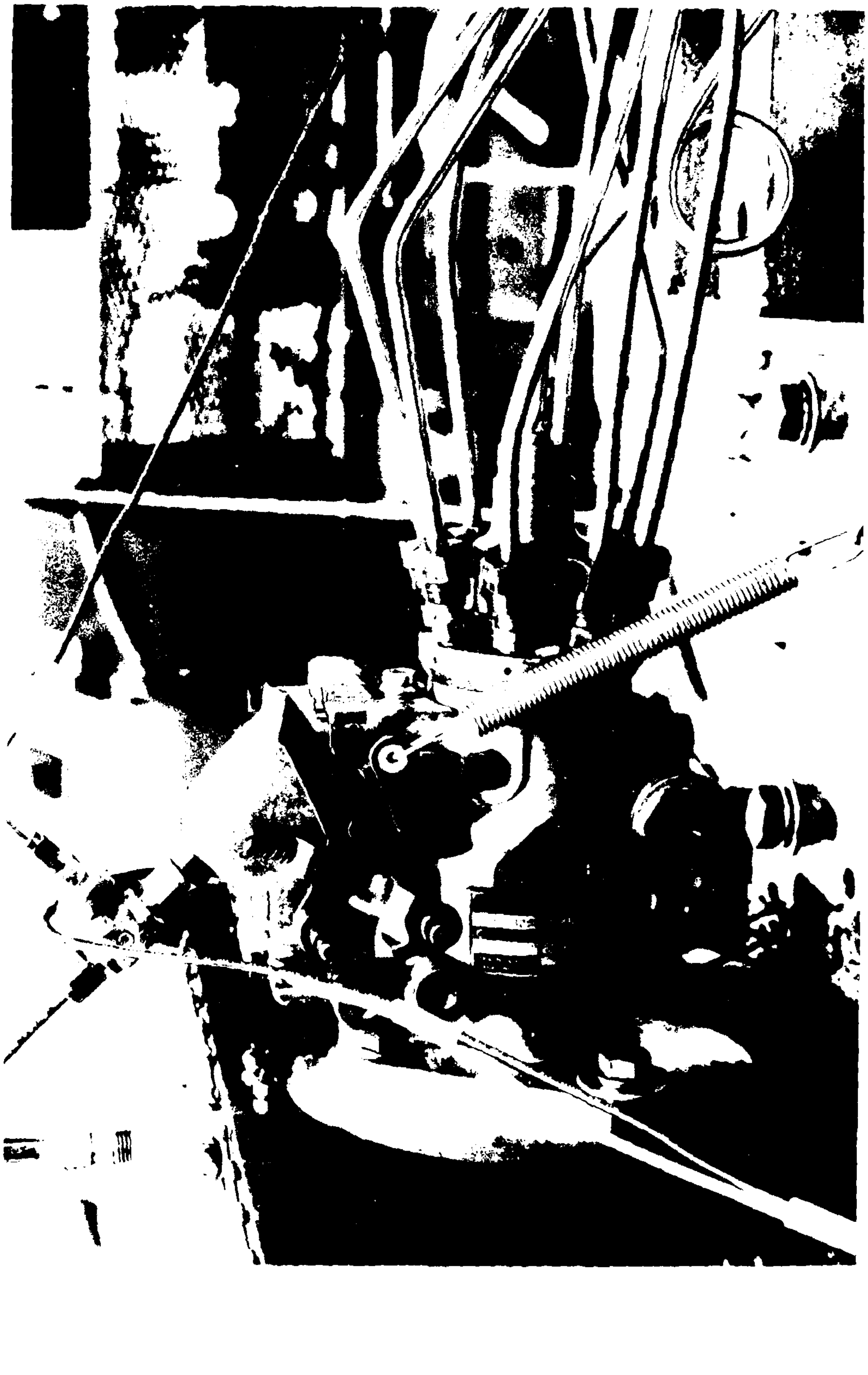


FIGURE 14. CETF WITH CUCV FUEL PUMP INSTALLED



3. Results and Discussion

a. AVDS 1790 Fuel System

Two 300-hr endurance tests were performed with the AVDS 1790 fuel system. Paraho-II DFM shale distillate (AL-10150-SP-F) was the fuel used in both runs. Throughout both tests, fuel samples were taken at 8-hr intervals to determine the lubricity of the test fuel as indicated by the BOCM.

It was originally intended that rig 2 was to be operated at a fuel lubricity level comparable to that of the Paraho-II DFM as received, namely, a BOCM wear scar of approximately 0.55 mm. It was planned to operate rig 1 with the test fuel clay treated to a BOCM value in the neighborhood of 0.65 mm. These objectives were only partially achieved and there was considerable fluctuation in the fuel wear characteristics throughout both endurance tests as shown by the plots of Figures 16 and 17. While other samples were taken at infrequent intervals from the fuel tank and the clay filter effluent, all data presented in these figures were for inlet fuel to the injection pump. Much of the difficulty in controlling fuel lubricity was due to the fuel response, or absence of response, to clay treatment. Adjustments in fuel flow rate through the clay appeared to be ineffective for a period of several hours after the action.

Problems associated with control of test fuel lubricity were probably compounded by the discovery during the tests that at least one clay charge supplied by the filter manufacturer was totally ineffective in modifying lubricity. The discovery was confirmed by opening an unused clay bag, packing a glass column, and percolating a test fuel sample through the clay using the procedure employed in the laboratory for treating small fuel batches. Duplicate BOCM tests with the filtrate showed no change in lubricity. Following this, all of the commercially-supplied bags were emptied and refilled with the Attapulgus clay used in laboratory work.

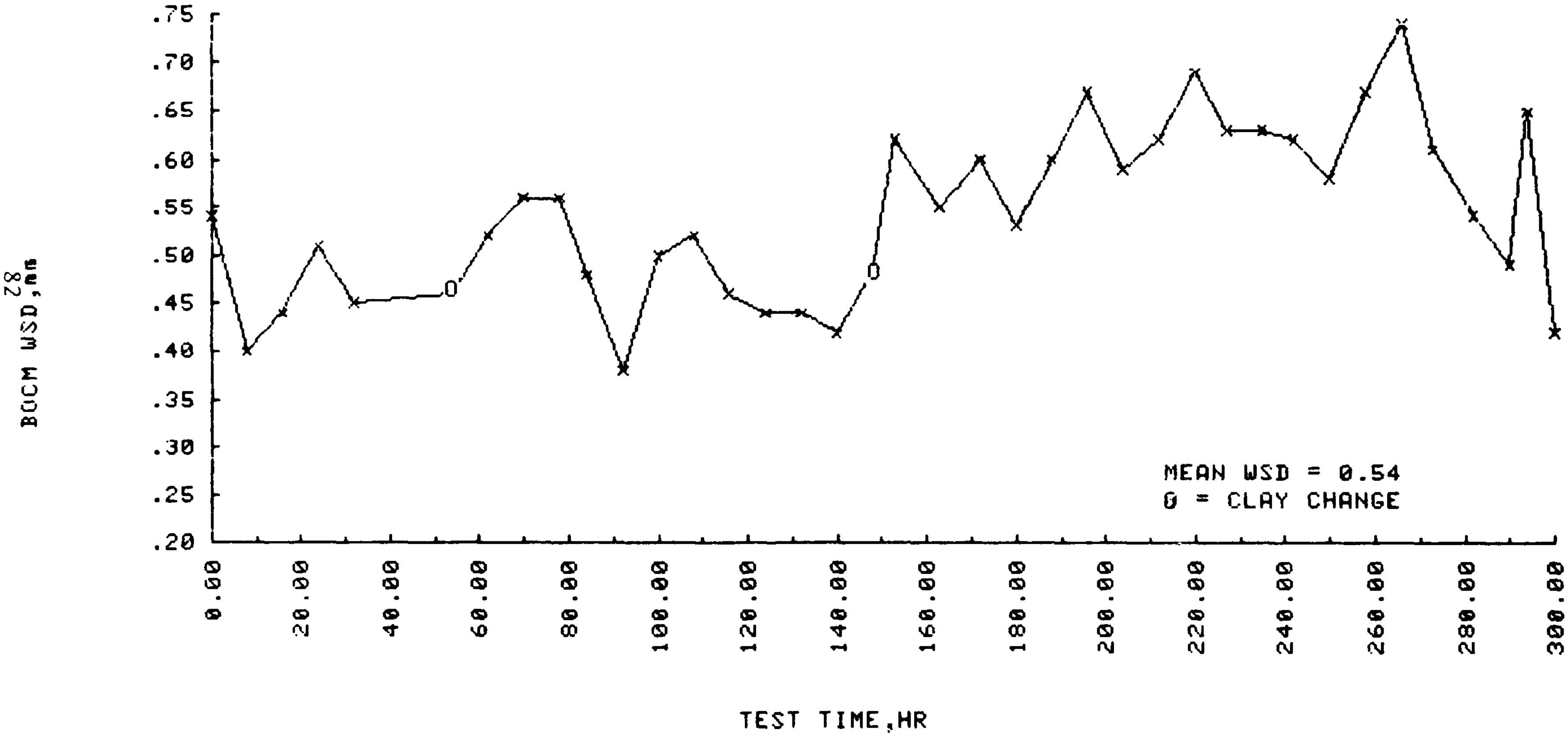


FIGURE 16. LUBRICITY RESULTS FOR AVDS 1790 ENDURANCE TEST FUEL — RIG 1

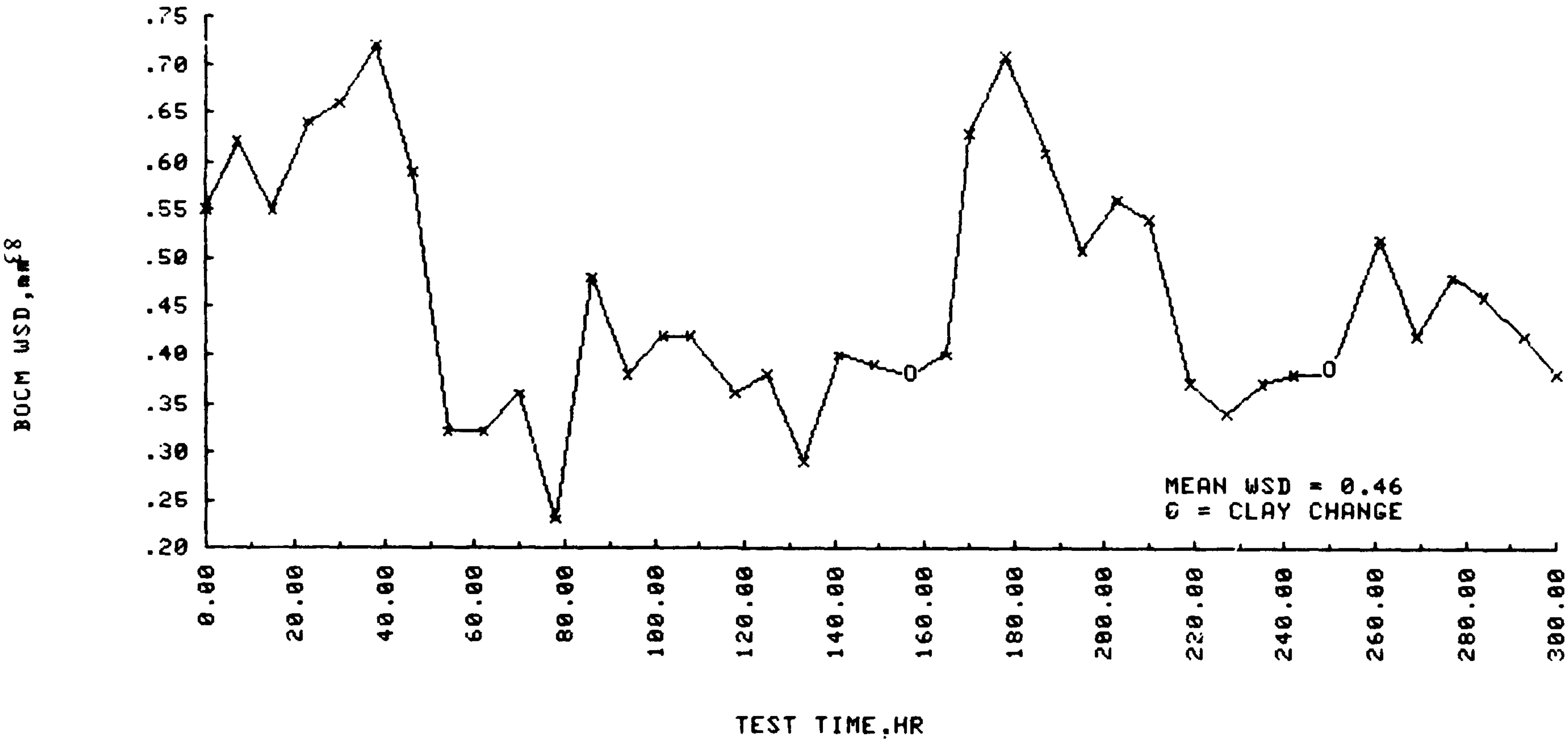


FIGURE 17. LUBRICITY RESULTS FOR AVDS 1790 ENDURANCE TEST FUEL — RIG 2

While planned levels of fuel lubricity were not sustained, mean wear scar values for the two runs over the 300-hr test period were 0.54 mm for rig 1 and 0.46 mm for rig 2. Subsequent student's t-analysis showed this difference to be significant for α = 0.001. This means that significant differential in lubricity was sustained throughout the test.

Prior to endurance testing, as previously noted, both AVDS 1790 fuel systems (serial numbers 7N54252 and 7N6694) were calibrated at the Ft. Hood maintenance facility to insure that fuel delivery met the applicable specifications. Although both units were new, it should be noted that minor adjustments were required for both injection pumps.

Upon completion of the 300-hr endurance tests, the pumps were returned to the Ft. Hood facility and operated through the same sequence of calibrations to determine the pumps' capability to function properly at different speeds and loads. It was found that both pumps met or surpassed all calibration standards at all test sequences and required no adjustments. The final requirement in the calibration sequence determines the pump's output to the injectors during engine cranking. If there is significant wear in the unit's hydraulic head, it will be evident during this operation. Specifications require that each fuel port deliver a minimum of 30 cm^3 of fuel after 500 strokes at 150 rpm. The lowest measured flow for the pump from CETF rig 1 was 54 cm^3. The average for all 12 ports was 71 cm^3, compared to a pretest average of 74 cm^3. The unit from rig 2 showed a minimum flow of 65 cm^3 and an average of 74 cm^3 of fuel. The pretest average for this pump was 69 cm^3. As a consequence of the evaluation performed, it was concluded that the condition of both pumps was comparable to that for new units.

During the post-test calibration, it was found that 10 of 24 fuel injectors failed to atomize. However, according to Ft. Hood personnel, this rate of injector failure in 300 hr is not unusual compared to the on-vehicle failure rate. Moreover, since the failure rate was equal (five each) for each injection pump, the cause of failure could not be attributed to differences in the condition of the test fuels used in the two CETF rigs.

Following the post-test calibration, the AVDS 1790 pumps were disassembled, elastomeric seals removed, and the elements evaluated for hardness change. All seals were Buna N O-rings. Shore A hardness data after test are compared with pretest values in Table 18. Pretest hardness was consistently in the range of 73-76 points and all seals softened 4-5 points which is not considered to be significant. All seals functioned satisfactorily throughout the 300-hr endurance tests.

TABLE 18. HARDNESS DATA FOR AVDS 1790 INJECTION PUMP SEALS

	Shore A Hardness, points			
	Rig 1		Rig 2	
Seal Location	Pre-test	Post-test	Pre-test	Post-test
Bleeder valve, housing	75	70	75	71
Bleeder valve, filter side	73	69	73	68
Fuel control	76	72	75	71
Front head	75	71	76	71
Rear head	75	70	75	70
Fuel filter	74	70	74	70

b. <u>6V-53T Fuel Pump</u>

Four endurance tests were completed with the 6V-53T engine fuel pump as the test specimen. Each test used a new pump with a a different fuel type or fuel treatment. These were Paraho-II DFM, Paraho-II DFM clay filtered, VV-F-800 DF-2, and JP-5 clay filtered. The petroleum DF-2 fuel was run to provide baseline performance information. The petroleum JP-5 fuel was evaluated to provide a

comparison with the clay-filtered Paraho-II since this JP-5 had demonstrated poor as-received lubricity. The two clay filtered runs were conducted using full-flow, continuous clay filtration in the inlet line to the fuel pump.

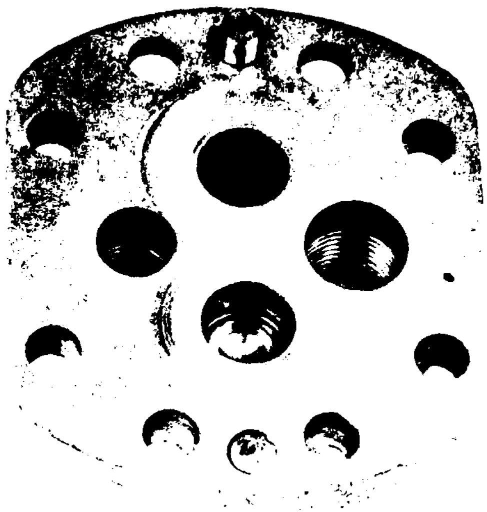
Table 19 presents the results of the four runs with the 6V-53T fuel pump. Average BOCM wear scar values are based on intermediate fuel samples taken during the runs. These data correlate very well with the ratings of wear which occurred between the rotating gear sides and the adjacent pump end plate surface. For all tests, this contact area exhibited the most severe mechanical distress. A lesser correlation is seen (Table 19) for BOCM results in comparison with the average scuffed area of the drive gear teeth. However, this comparison is complicated by the early pump seizure which occurred with the clay-filtered Paraho-II fuel. The apparent point of seizure was in the high wear area between the gear sides and the end plate.

TABLE 19. 6V-53T FUEL PUMP ENDURANCE TEST RESULTS

Test Fuel (Code)	Test Time, hr	Avg BOCM WSD, mm	Avg Gear Tooth Scuff, %	Visual Rating of End-Plate Wear	Test No.
Paraho-II DFM, (AL-10150)	300	0.4	33	Light	1
Paraho-II DFM, clay filtered (AL-10150)	69*	0.6	34	Severe	2
VV-F-800, DF-2 (AL-10187)	304	0.3	43	Negligible	4
JP-5, clay filtered (FL-0203)	306	0.7	73	Severe	5

* Pump seized at 69 hours

Figures 18 through 21 contain photographs of the worn pump end plates for the 6V-53T test series, along with corresponding instrumental surface traces. The traces



TEST 1

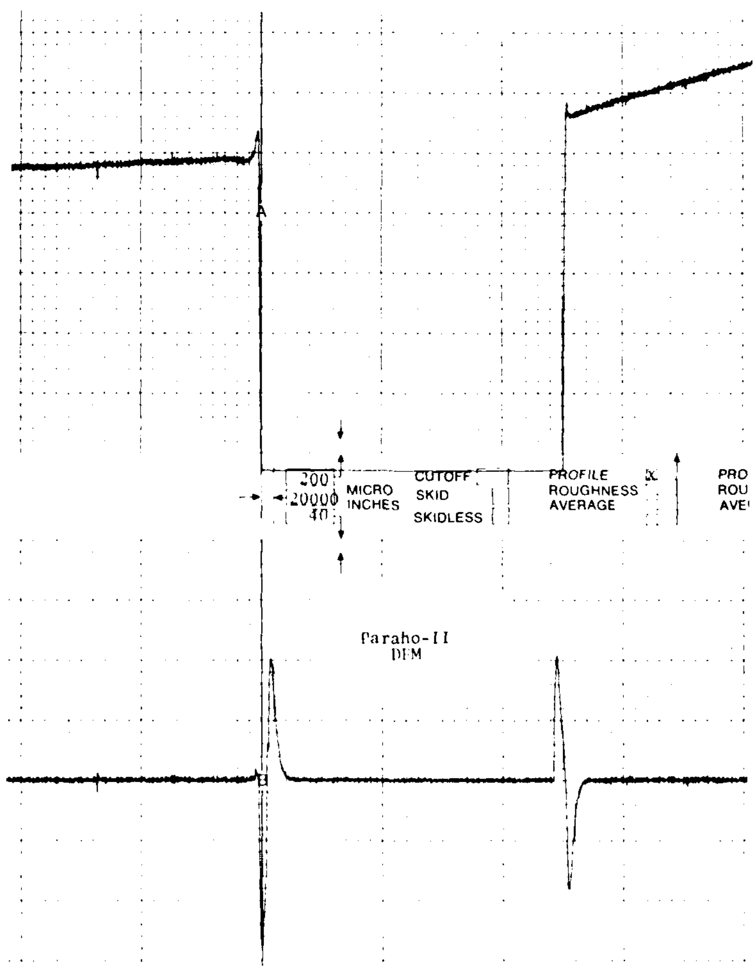
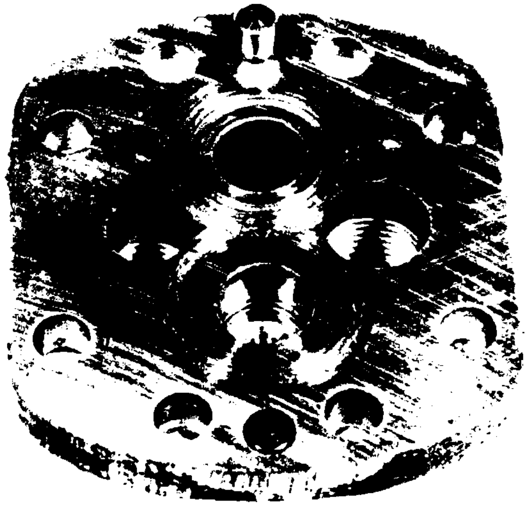


FIGURE 18. PUMP END-PLATE CONDITION WITH PARAHO-II DFM TEST FUEL



TEST 2

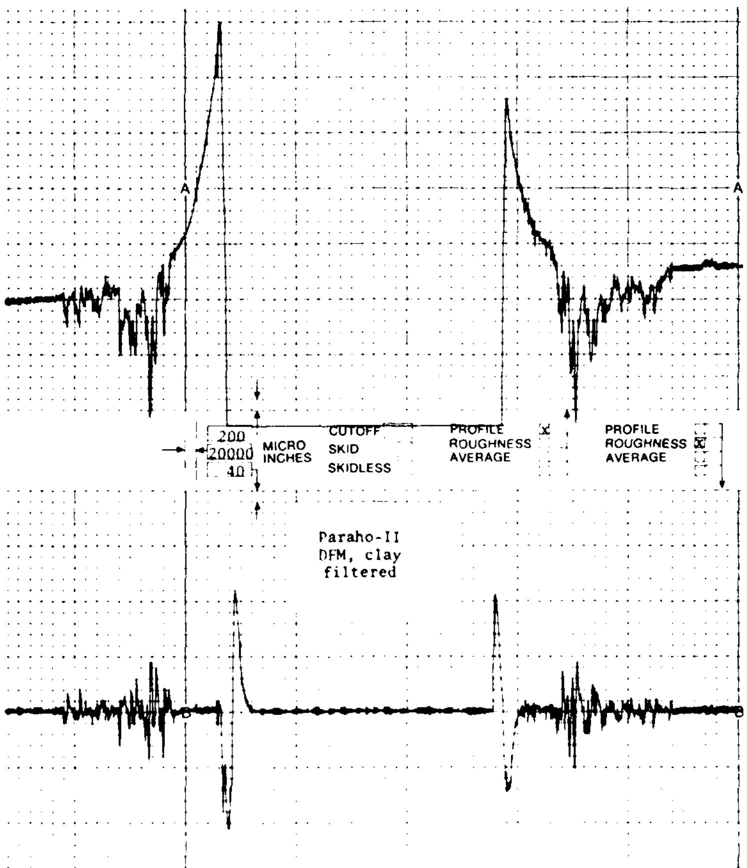
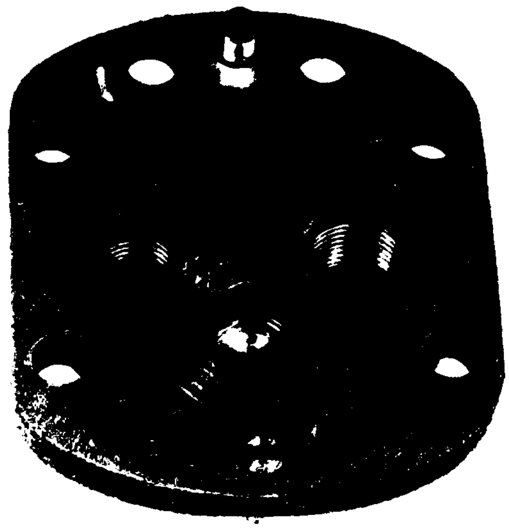


FIGURE 19. PUMP END-PLATE CONDITION WITH CLAY FILTERED PARAHO-II TEST FUEL



TEST 4

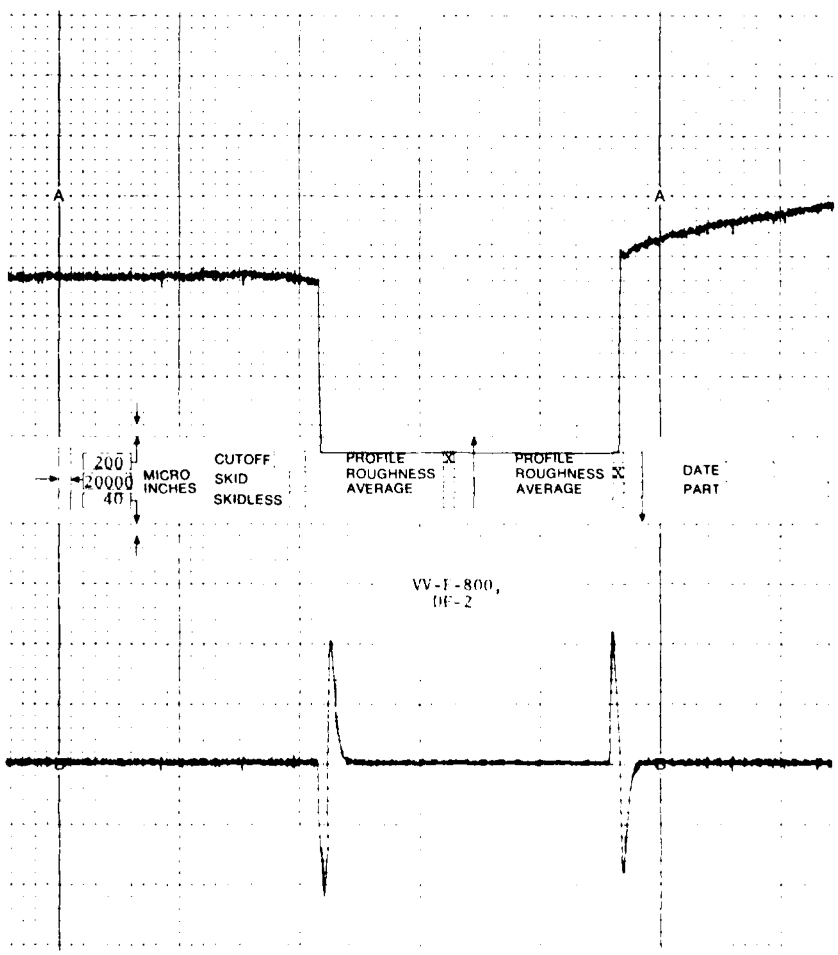
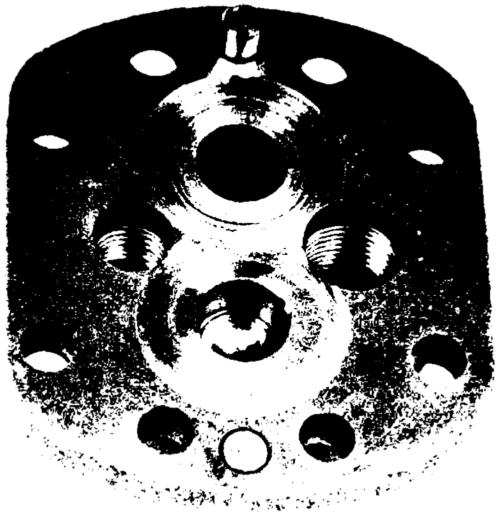


FIGURE FUEL 20. PUMP END-PLATE CONDITION WITH DF-2 TEST FUEL



TEST 5

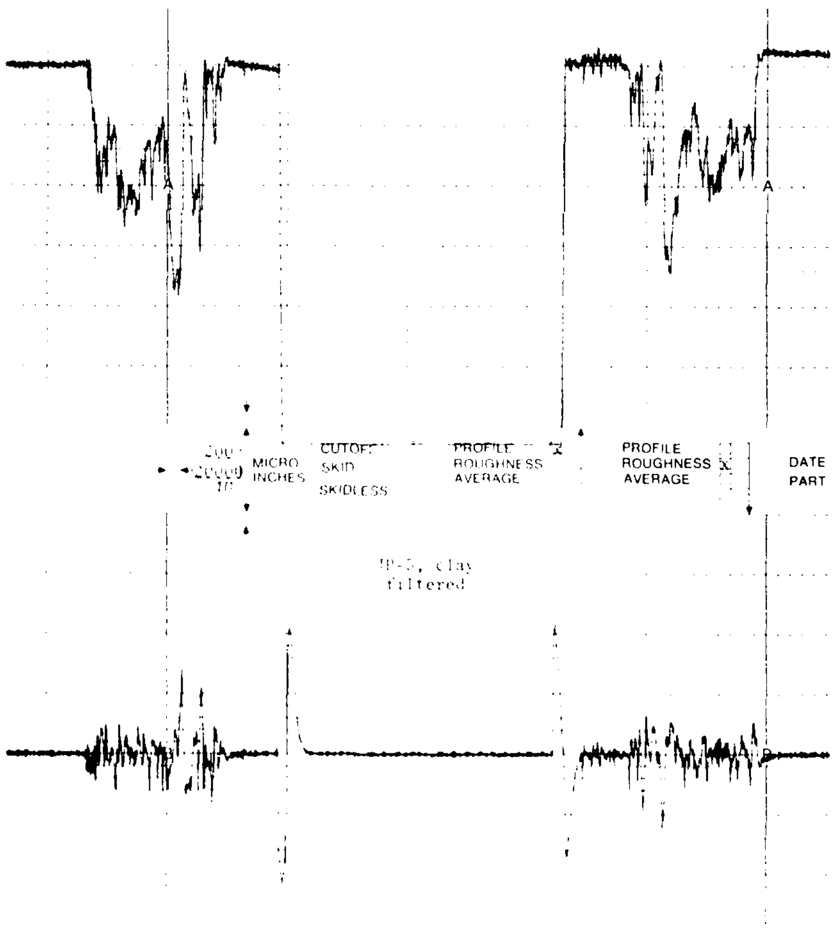


FIGURE 21. PUMP-END PLATE CONDITION WITH CLAY FILTERED JP-5 TEST FUEL

were taken with a Gould Surface Analyzer across the plate wear area generated by the drive gear (the upper circular wear track in the photographs).

The upper trace describes the surface profile, while the lower trace is a surface roughness measure about a baseline. The central section in each trace and the two extreme up-and-down peaks shown in the roughness traces define the gear shaft hole.

The surface traces for the two low-wear tests with Paraho-II DFM (Fig. 18) and VV-F-800 DF-2 (Fig. 20) did not distinguish between the tests as to the extent of wear. However, the photographs and visual rating indicated slightly greater wear with Paraho-II. Significant wear distress occurred with the two clay-filtered fuels, as seen in Figures 19 and 21. Neglecting the spurious peaks due to the shaft hole, the maximum measured roughness was approximately 220 microinches for Paraho-II and 280 microinches for the JP-5 fuel. These data, and especially the visual wear ratings, lend credence to the capability of the BOCM to measure fuel lubricity characteristics and provide testimony to the fuel sensitivity of the 6V-53T gear pump.

c. NHC 250 Injector Pump

Two parallel runs were completed for this pump type using the Paraho-II shale diesel fuel. Full-flow clay filtration of the test fuel was performed for one test. Test fuel lubricity was monitored at 25-hr intervals by BOCM evaluation of fuel aliquots.

Table 20 lists BOCM wear data for both tests and Figure 22 presents a plot of these values against test time. A "t-statistic" for data up to the 300-hr endurance point yielded a value of 2.982 which reflects a very high probability (α=0.01) that the WSD means were significantly different, i.e., lubricity was controlled by clay treatment on the second rig at a significantly poorer level than for the test run with

TABLE 20.
LUBRICITY DATA FOR NHC 250 TEST FUEL SAMPLES
(PARAHO-II DFM)

Test Time, hr		BOCM WSD, mm	
		Neat Fuel	CT Fuel
0		0.50	0.49
25		0.50	0.57
50		0.60	0.55
75		0.48	0.48
100		0.52	0.50
125		0.39	0.51
150		0.42	0.50
175		0.45	0.48
200		0.40	0.60
225		0.50	0.58
250		0.44	0.59
275		0.42	0.48
300		0.42	0.51
325			0.39
350			0.36
375			0.46
400			0.55
425			0.36
450			0.46
475			0.46
500			0.50
	Mea..	0.46	0.49

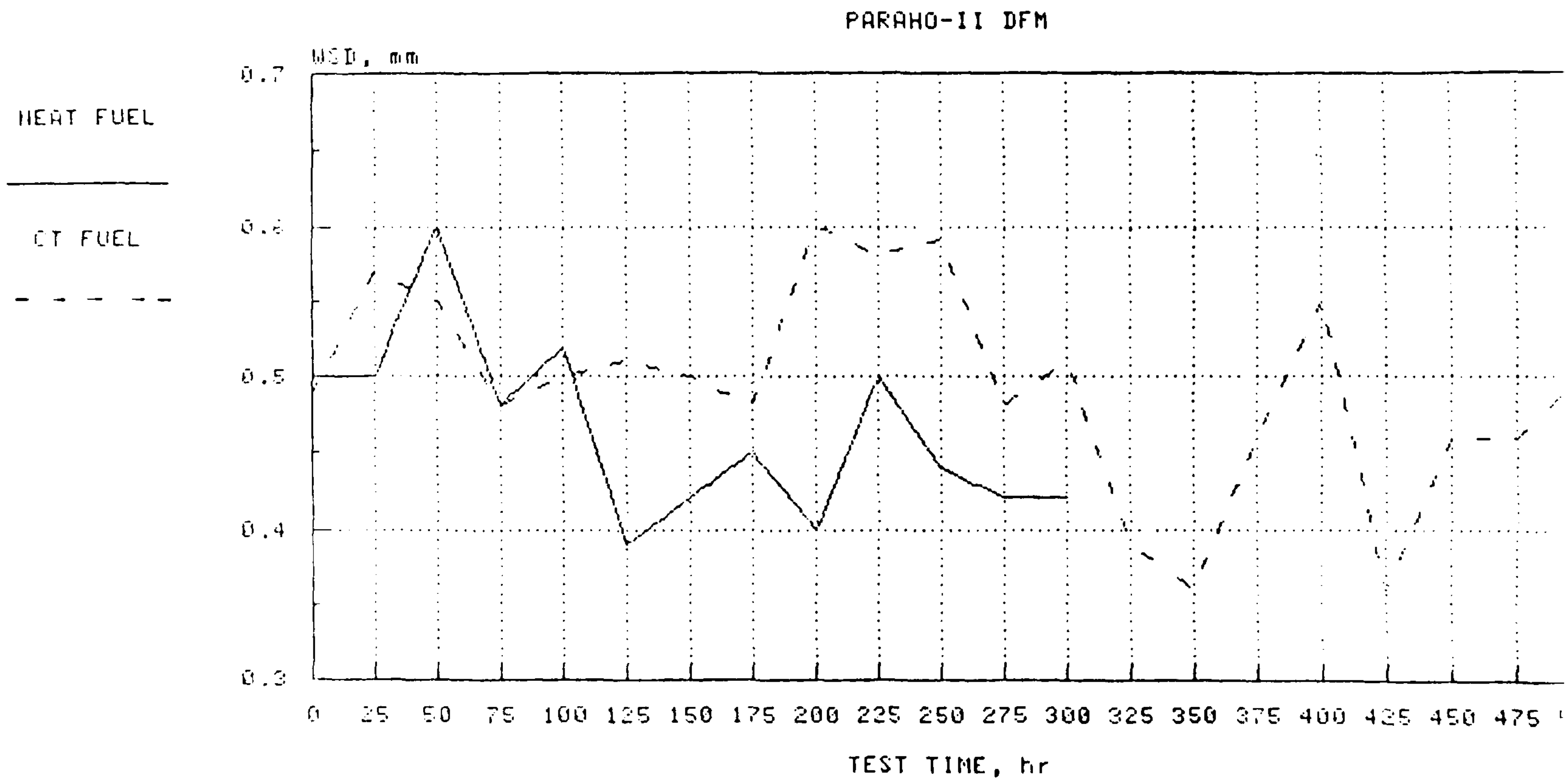


FIGURE 22. BOCM DATA FOR NHC-250 TEST FUEL SAMPLE

AD-A143 845 DEVELOPMENT OF ACCELERATED FUEL-ENGINE QUALIFICATION PROCEDURES(U) SOUTHWEST RESEARCH INST SAN ANTONIO TX J A RUSSELL ET AL. SEP 83 SWRI-6797/4 DAAK70-81-C-0209 2/2

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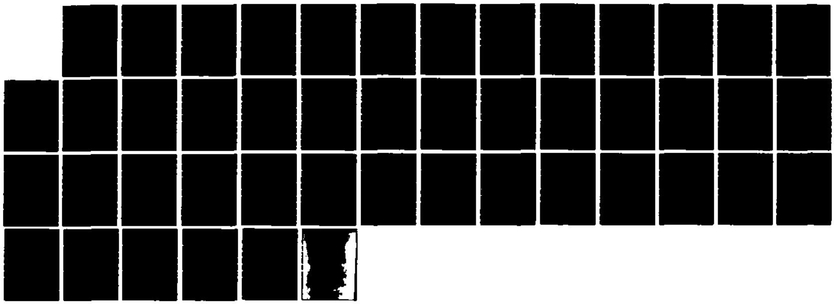

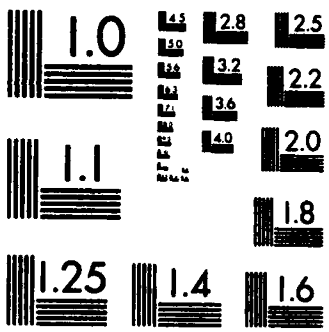

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963 A

neat fuel. Figure 22 also indicates that the untreated fuel showed improved lubricity after 100-hr of test time. Presumably, this occurred as a consequence of some degradation of the test fuel.

Pump operation for both rigs was routine throughout the 300-hr duration of each test. Upon completion of testing, both units were returned to Ft. Hood and again subjected to the rebuild facility test stand checkout procedure. Both pumps met or surpassed all performance requirements; subsequent disassembly and inspection of the unit operated with neat (non clay-filtered) Paraho-II DFM revealed no visible mechanical distress or significant wear of fuel-wetted elements. Similarly, there was no visible evidence of any seal malfunction with the disassembled pump. All sealing elements from this unit were retained, but elastomer properties were not measured since new property baseline data for these elastomers were not available at Ft. Hood.

Discussions with Ft. Hood maintenance personnel revealed that the normal time-between-overhaul for this pump is in excess of 300 hr. For this reason, a supplementary 200-hr of endurance testing was executed on the NHC 250 fuel pump which had not been disassembled, using the clay-treated Paraho-II DFM fuel. Again, operation of this pump during this supplementary testing was routine with no apparent external problems. Upon completion of the grand total of 500-hr of endurance testing on this single pump, the unit was returned to Ft. Hood for post-test checkout, disassembly and inspection.

The pump met all calibration standards with the exception of the Governor Cutoff RPM Test and the Throttle Leakage Test. The governor cutoff rpm test determines the rpm at which the governor begins to reduce the fuel pressure in case of excessive engine speed. Calibration test standards require for fuel shutoff to begin

when the pump reaches a speed of 2130-2150 rpm. The pump being tested reached a speed of 2300 rpm before the fuel pressure started to drop. The throttle leakage test determines the deceleration time of the engine. Test standards require that with the pump operating at 2100 rpm and the throttle moved from full fuel to the idle position, and after one minute of test stand operation, the fuel delivery should be from 32-36cc. The fuel delivery of the pump being tested was an average of 73cc. (Three separate leakage tests were performed and the fuel delivery for each was 73, 78 and 68 cc respectively.)

There are adjustments that can be made to correct each of the above deficiencies to bring them within calibration standards; however, the objective of this post endurance calibration test was to determine the cause of any deficiencies found during the test. Therefore, the pump was removed from the test stand and disassembled without making any adjustments.

After the pump was disassembled and a visual inspection made of the components, it was found that the thrust washer and the driver in the governor plunger assembly were excessively worn. This wear in the plunger assembly, according to Ft. Hood personnel, in all probability, accounted for the calibration failures referred to above.

The disassembled parts and elastomers from the NHC 250 units were tagged and returned for further analyses. Ft. Hood personnel provided a replacement seal kit to be used for baseline comparison to elastomer hardness measurements on the used seals. Table 21 presents comparative data for corresponding new and used seals. These results indicate no compatibility problems between the elastomeric pump components and the Paraho fuel.

TABLE 21.
ELASTOMER COMPONENT HARDNESS CHANGE FOR NHC 250 PUMP AFTER 500-HR TEST WITH CLAY-FILTERED PARAHO -II DFM (All Data Shore A Hardness)

FUEL OUTLET SEAL

BEFORE	AFTER
73	79
74	78
74	79
73	80
75	78

FUEL INLET SEAL

BEFORE	AFTER
* No data available	80
	82
	81
	82
	82

THROTTLE SHAFT SEAL

BEFORE	AFTER
72	77
75	76
75	76
77	75
76	76

PULSATING DAMPENER SEAL

BEFORE	AFTER
76	75
77	77
75	77
76	76
76	77

FUEL FILTER (large) SEAL

BEFORE	AFTER
75	76
73	77
74	76
73	76
73	76

TABLE 21 Cont'd.

FUEL FILTER (small) SEAL

BEFORE	AFTER
75	76
75	75
73	76
75	75
75	76

BYPASS VALVE (large) SEAL

BEFORE	AFTER
73	77
76	77
74	75
74	77
74	76

BYPASS VALVE (small) SEAL

BEFORE	AFTER
77	79
75	80
76	81
73	80
77	81

MAIN SHAFT SEALS

BEFORE	AFTER
91	89
93	90
91	89
91	89
93	90

d. LDT 465-1C Injectors and Pumps

The results for this fuel systems were reported under an earlier program[2]. The findings of that study are briefly summarized here for the purpose of completeness. Two tests were carried out using the Paraho-II diesel fuel, with and without clay filtration. Both test systems successfully completed 500-hr of operation. Post-test calibration checks by Ft. Hood maintenance personnel showed that the unit run with neat fuel met or surpassed all minimum standards. The pump operated with clay-treated fuel did not meet the minimum flow requirement for two of the six hydraulic head ports. Through minor adjustments, the proper flow was achieved and the unit was rated a "marginal pass".

Both pumps showed excessive overall swell of a static Buna-N seal in the hydraulic head.

e. CUCV Pump/Injectors

One 300-hr test at rated conditions was performed with the CUCV unit using partial clay filtration of the Paraho-II diesel fuel. The lubricity of the test fuel was evaluated at 25-hr intervals by the BOCM, with the objective being to maintain the fuel near a WSD of 0.5 mm. This was, in fact, accomplished as evidenced by a mean value of 0.51 mm and a standard deviation of 0.05 mm for the 13 samples taken during the run.

The 300-hr test was completed without incident. However, post-test examination of the pump revealed several areas of mechanical distress. Severe scuffing of the transfer pump blades occurred in the area of blade contact with the

driving rotor. Significant wear was also noted for all eight cam lobes of the cam ring. One of the two cam rollers and associated cam roller shoe showed appreciable damage. The roller indicated severe metal loss over approximately ten percent of its surface. The distress was believed to be best described as delamination type wear. Inspection of the pump by diesel engine technicians who have considerable experience with the unit elicited the statement that the overall condition of the pump was equivalent to 100,000 miles of operation.

IV. FULL-SCALE ENGINE TESTS

As part of prior work[2] performed under Contract DAAK70-80-C-0001 which laid the groundwork for this current activity, a thorough assessment was made of diesel engines (and fuel system components thereof) which power current U.S. Army tactical and combat ground vehicles. Based on that assessment, it was concluded that fuel consumption and vehicle usage were two of the most important factors upon which development of the AFQP should be based. In addition, it was felt important that development of the AFQP should be accomplished with engines representative of Army-designed configurations as well as commercially available derivatives. For these reasons, the engines recommended as the basis for continuing the development of the AFQP are as shown in Table 22 and were recommended because they represent:

- The vast majority of diesel engines used to power Army M-series combat and tactical vehicles.
- The broadest range of Army-designed and commercial derivative diesel engines.
- One of a family of engines with very similar characteristics, components, and engine manufacturers. For example, the DDA 6V-53 series engine is available in both naturally aspirated and turbocharged configurations. In addition, the 6V-53 series engine is very similar to larger displacement DDA engines and uses derivative fuel system components from other DDA diesel engines.
- Both naturally aspirated and turbocharged engine configurations.
- The three largest suppliers of Army engines.
- A well-documented history of past performance and qualification testing.
- An engine family (LD, LDS, LDT-465 series) with existing "multi-fuel" capability.

TABLE 22. ENGINE NOMINEES TO SUPPORT DEVELOPMENT OF THE AFQP

Manufacturer	Engine	M-Series Vehicle Designation
Teledyne Continental Motors	AVDS 1790 Series	M48A4, M60A1, M50A1, RISE, M50A2, M60A3 M88A1, M728
Teledyne Continental Motors	LD/LDT/LDS-465 Series	M35As, M35A2C, M36A2, M44A2, M45A2, M45A2C, M46A2, M46A2C, M49A2C, M50A2, M50A3, M109A2, M195A3, M275A2, M292A2, M292A5, M342A2, M751A2, M756A2, M763, M764, M40A2C, M51A2, M52A2, M54A2, M54A2C, M55A2, M61A2, M63A2, M63A2C, M246A2, M291A2,M291A2C,M291A2D, M328E2, M543A2, M738E2, M748A2, M656, M757, M791
Detroit Diesel Allison	6V-53 and 6V-53T	M106A1, M113A1, M125A2, M132A1, M548, M577A1, M667, XM727, M730, M741, XM806E1, M551, M551A1
Cummins Engine Co.	NHC-250	M813, M813A1, M814, M815, M816, M817, M818, M819, M820, M821

Except for the Cummins NHC-250, all other engines are available at SwRI for testing and evaluation. If time and funds permit under future program activities, this engine will also be considered for testing.

Fuel system components used with the engines have also been selected for evaluation and use in developing the AFQP. Without detailing each item specifically, those components generally include: injection pumps, unit injectors, nozzles, fuel supply pumps, hoses, lines, filters, strainers, solenoid valves, and manifold heaters.

Procedures

Hundreds of diesel engine qualification tests have been performed over the years, by both the Army and engine manufacturers. Additionally, several types of qualification procedures have been agreed to as providing representative data on an engine's ability to perform adequately with specification-grade diesel fuel. Some engines have undergone limited qualification testing on "relaxed-specification" diesel-type fuels are expensive and that full-scale engine tests require much time to accomplish, we have, as with components testing, recommended a rational approach to engine testing. The intent is to draw from past experience (vis-a-vis engine qualification procedures), add to it results from the component bench-scale testing portion of this program and use both as the basis for the AFQP. Referring to the predecessor work on this program, two engine endurance test procedures seemed most relevant as a starting point - the NATO 400-hr test and the Army 500-hr Mission Cycle Test. Table 23 shows which of the candidate engines have completed either of the 400-hr or 500-hr endurance tests. Since most of the candidate engines have completed the 500-hr test and this test is judged to be somewhat more rigorous than the 400-hr NATO cycle, the 500-hr Mission Cycle endurance is the first choice for establishing an engine-level durability basis for the AFQP. Details of the test procedure, conditions,

TABLE 23. ENGINE/MANUFACTURER MATCHES AND ENGINE ENDURANCE TEST

Engine Manufacturer	Engine Designation	Specification or Purchase Description Designation	Test Completed
Teledyne Continental Motors	AVDS-1790 Series	MIL-E-62177(AT)	400 Hour
White Motors & Teledyne Continental Motors	LD-465-1 and LD-465-1A	MIl-E-62106(AT)	500 Hour
	LDS-465-A & LDS-465-1A	DAPD-292F	500 Hour
	LDS-465-2	ATPD-2024A	500 Hour
	LDT-465-1C	ATPD-2046	500 Hour
Detroit Diesel Allison	6V-53	MIL-E-62140(AT)	500 Hour
	6V-53T	MIL-E-5239A	400 Hour
Cummins Engine Company	NHC-250	ATPD-2083B	500 Hour

and post-test examinations are described in Reference 2, Volume II, which is the final report on the predecessor project.

In actual application of the AFQP screening process, full-scale engine testing would be performed only as needed. Thus, full-scale engine tests would be performed as the final discriminator to determine fuel property and engine parameter acceptability. At this time, it is not possible to determine if the complete 500-hr Mission Cycle endurance test (or 400-hr NATO cycle test) will be needed as an integral part of the AFQP. Obviously, it is desirable to incorporate within the AFQP as short an engine test procedure as is practical.

Consideration was given to adopting a 200-hr preliminary durability screening test suggested by the Engine Manufacturers Association (EMA) for evaluating vegetable oils. Since full-scale testing of Army engines has not been conducted as part of the current program effort, it was (and still is) difficult to determine if the proposed EMA screening test, or any other more abbreviated durability cycle can be adapted for AFQP use. Full-scale engine testing, as part of subsequent work is required in order to establish the extent, length, and rigor of full-scale engine tests sequence to be contained within the AFQP.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Since the purpose of this program has been to develop technological capabilities rather than to perform fundamental research, the following conclusions are phrased in terms of either significant capabilities which have been developed or in terms of key properties which seem to be critical to Army utilization of future fuels via AFQP screening:

- The BOCM apparatus and procedure shows good promise for measurement of fuel lubricity. Correlation with diesel injector pump wear in component testing is good, but correlation with pump wear during full-scale engine testing actual has yet to be established.
- Adaptation of the widely-employed JFTOT apparatus and procedure for measurements of thermal stability, elastomer compatibility and elastomer leachate effects upon thermal stability should result in a straightforward methodology for bench testing of these key properties. As with the BOCM, correlation with full-scale engine results is paramount prior to instigation of such procedures in Army procurement of new fuels.
- Certain elastomers currently widely employed in Army tactical and combat mobile systems may be incompatible with future liquid hydrocarbon fuels having extreme variations in composition.
- Routine evaluation for lubricity properties of the several fuels examined in this program identified only the Paraho-II DFM as an inherently poor lubricity fluid. The Sasol diesel and gasoline fuels derived from coal both indicated good lubricity characteristics.
- BOCM data for a series of isooctane/toluene blends showed a beneficial synergistic effect on wear due to blending.

- Attempts to develop a multi-metal static corrosion test method resulted in only marginal test repeatability. However, with the fuels evaluated thus far, only copper or copper alloys have indicated measurable corrosion and the susceptibility was adequately identified by the standard ASTM procedure (D 130).
- Component evaluations using an intentionally lubricity-degraded shale test fuel (Paraho II) has identified certain diesel pumps to be lubricity-sensitive while others are apparently insensitive. **It should be emphasized that the component endurance effort was undertaken with the intention of demonstrating correlation with the much simpler BOCM device which would be much more practical in a fuels screening methodology.** Component evaluations classified the following engine fuel pumps with respect to fuel lubricity sensitivity:

AVDS 1790	No
6V-53T	Yes
NHC 250	No
LDT 465-1C	Marginal
CUCV	Yes

In the case of the 6V-53T and CUCV fuel pumps, an acceptable fuel lubricity criterion would be a BOCM WSD of ≤ 0.50 mm.

B. Recommendations

The key word in the AFQP effort is "accelerated". Each individual activity under this program should contribute to the concept of minimizing the time, labor, and fuel needed to qualify new and/or alternative fuels. In addition, testing protocol should be based to the maximum extent possible on standard tests which eventually

could be performed by quality surveillance organizations. This present program has developed laboratory techniques based upon relatively simple and widely used apparatus and procedures. Correspondingly, these apparatus/procedures have been used to test as wide a variety of alternative fuels and typical petroleum diesel fuels as could be accomodated during FY1982-83. A more comprehensive database using the AFQP methodologies developed to date must be generated, employing state-of-the-art non-petroleum and petroleum fuels considered to be either marginal or suspect for Army utilization. In this context, it is recommended that the following activities be undertaken:

- Procurement of state-of-the-art fuels for proof-testing (i.e, "testing the test" as regards AFQP methodologies)
- Further replicative testing for all laboratory and bench techniques to better define both repeatability and identify pass/fail criteria
- Initiation of full-scale engine testing, utilizing those engines of most immediate interest to the Army (ie., from the standpoints of density, mission criticality and fuel sensitivity).

At the time of this writing, it is understood that a continuation of this effort will take place during FY1984-85 at the U.S. Army Fuels and Lubricants Research Laboratory located at Southwest Research Institute, with management and overall direction from Belvoir R&D Center. Further, it is understood that the key objectives of this continuing effort will be much as described by the above recommendations. It is felt that this will eventually result in a viable coordinated Accelerated Fuel-Engine Qualification Procedure.

VI. LIST OF REFERENCES

1. LePera, M.E., "The U.S. Army's Alternative and Synthetic Fuels Program," Army Research, Development, & Acquistion Magazine, pp 18-20, September-October 1980.

2. Russell, J.A., Cuellar, J.P., Jr., Tyler, J.C., et al., "Development of Accelerated Fuel-Engines Qualification Procedures Methodology", AFLRL Report No. 144, December 1981, Government Accession No. AD A113461.

3. Sefer, N.R., and Russell, J.A., "Formulation and Evaluation of Highway Transportation Fuels from Shale and Coal Oils", Second Annual Report, Contract No. DE-AC01-79CS-50017, December 1981.

4. Grabel, L., "Lubricity Properties of High Temperature Jet Fuel", NAPTC-PE-112, August 1977.

5. Appeldoorn, J.K., and Tao, F.F., "Lubricity Characteristics of Heavy Aromatics", Wear, Vol. 12, pp. 117-130, 168.

APPENDIX A
DIESEL/BROADCUT/REFERENCE FUEL DATA

APPENDIX A TABLES

TABLE A.1 JFTOT/TOFT SUMMARY DATA

FUEL CODE	FUEL TYPE	MAX RATING VISUAL	MAX RATING SPUN TDR	FILTER ΔP, mmHG/minutes
		STANDARD JFTOT		
AL-10115-SP-F	PETRO CAT 1-H	4	26	125/82
AL-10150-SP-F	PARAHO-II DFM	0	0	0/150
AL-10289-SP-F	SRC-II,MEDCETANE	4	50+	125/6
AL-10286-SP-F	PETRO BCF	2	9	0/150
AL-10305-SP-F	SHALE BCF	4	15	125/85
AL-10306-SP-F	COAL BCF	3	12	0/150
		TOFT,150F SUMP		
AL-10115-SP-F	PETRO CAT 1-H	4	17	125/53
AL-10150-SP-F	PARAHO II DFM	0	0	0/150
AL-10289-SP-F	SRC-II,MEDCETANE	4	50+	125/4
AL-10286-SP-F	PETRO BCF	3	9	125/117
AL-10305-SP-F	SHALE BCF	4	19	54/150
AL-10306-SP-F	COAL BCF	3	12	10/150
		TOFT,150F SUMP,CT FUEL		
AL-10115-SP-F	PETRO CAT 1-H	2	9	1/150
AL-10150-SP-F	PARAHO II DFM	0	0	0/150
AL-10289-SP-F	SRC-II,MEDCETANE	4+	50+	125/43
AL-10286-SP-F	PETRO BCF	1	9	0/150
AL-10305-SP-F	SHALE BCF	2	9	125/113
AL-10306-SP-F	COAL BCF	1	2	0/150
		TOFT,150F SUMP,DOUBLE CT FUEL		
AL-10289-SP-F	SRC-II,MEDCETANE	4+	50+	125/40

TABLE A.2 THERMAL STABILITY DATA FOR BASELINE AND ELASTOMER TOFT TESTS FOR DIESEL AND BROADCUT TEST FUELS

TOFT TEST	ELASTOMER	SPUN TDR	VISUAL DEPOSIT RATING, ASTM NO.	mmHG	MINUTES
		AL-10115-SP-F CAT 1 H DF-2			
T-7	BASE	17	<4	125	53
T-45	VITON	29	4	125	30
T-34	N219-7	26	4	125	44
T-39	BUNA N70	26	4	125	44
T-20	F-SILICONE	18	4	125	66
		AL-10150-SP-F PARAHO II DFM			
T-23	BASE	0	0	0	150
T-46	VITON	0	0	3	150
T-33	N219-7	3	1	0	150
T-40	BUNA N70	3	1	0	150
T-27	F-SILICONE	1	1	0	150
		AL-10286-SP-F BCF-1			
T-24	BASE	15	3	10	150
T-47	VITON	15	4	125	143
T-35	N219-7	16	3	125	140
T-41	BUNA N70	15	2	125	134
T-28	F-SILICONE	13	3	95	150

TABLE A.3 THERMAL STABILITY DATA FOR BASELINE AND ELASTOMER TOFT TESTS FOR DIESEL AND BROADCUT TEST FUELS

TOFT TEST	ELASTOMER	SPUN TDR	VISUAL DEPOSIT RATING, ASTM NO.	mmHG	MINUTES
		AL-10289-SP-F SRC-MEDCETANE			
T-12	BASE	+50	+4	125	4
T-50	VITON	+50	+4	125	4.2
T-38	N219-7	+50	+4	125	3
T-44	BUNA N70	+50	+4	125	2.9
T-31	F-SILICONE	+50	+4	125	3
		AL-10305-SP-F BCF-2			
T-11	BASE	19	+4	54	150
T-49	VITON	19	4	0	150
T-37	N219-7	19	3	0	150
T-43	BUNA N70	21	3	16	150
T-30	F-SILICONE	20	4	115	150
		AL-10306-SP-F BCF-3			
T-10	BASE	12	3	10	150
T-48	VITON	28	3	57	150
T-36	N219-7	15	3	125	55
T-42	BUNA N70	10	>2	115	150
T-29	F-SILICONE	10	2	0	150

TABLE A.4 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10115	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.853	2.7	-6.0
SAMPLE 2	1.848	3.6	-6.0
SAMPLE 3	1.844	3.6	-8.0
AVERAGE	1.848	3.3	-6.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10150	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.852	2.9	-10.0
SAMPLE 2	1.820	-2.1	-6.0
SAMPLE 3	1.821	-2.4	-7.0
AVERAGE	1.831	-0.5	-7.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10286	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.832	1.5	-2.0
SAMPLE 2	1.835	0.7	-7.0
SAMPLE 3	1.837	0.6	-7.0
AVERAGE	1.835	0.9	-5.3

TABLE A.5 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10306	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.846	2.7	-5.0
SAMPLE 2	1.847	6.2	-3.0
SAMPLE 3	1.840	3.2	-3.0
AVERAGE	1.844	4.0	-3.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10305	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.845	2.8	-7.0
SAMPLE 2	1.835	1.8	-3.0
SAMPLE 3	1.831	1.0	-1.0
AVERAGE	1.837	1.9	-3.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10289	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.838	1.7	-4.0
SAMPLE 2	1.842	2.3	-1.0
SAMPLE 3	1.849	2.6	-5.0
AVERAGE	1.843	2.2	-3.3

TABLE A.6 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10115	N-219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.298	5.2	-5.0
SAMPLE 2	1.302	4.2	-3.0
SAMPLE 3	1.231	6.3	-4.0
AVERAGE	1.277	5.2	-4.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10150	N-219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.294	2.4	0.0
SAMPLE 2	1.291	1.8	0.0
SAMPLE 3	1.291	2.4	-4.0
AVERAGE	1.292	2.2	-1.3

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10286	N-219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.297	11.8	-9.0
SAMPLE 2	1.300	12.0	-7.0
SAMPLE 3	1.301	11.1	-9.0
AVERAGE	1.299	11.7	-8.3

TABLE A.7 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10306	N-219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.207	14.7	-2.0
SAMPLE 2	1.219	15.5	-2.0
SAMPLE 3	1.287	10.6	1.0
AVERAGE	1.238	13.6	-1.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10305	N-219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.289	11.1	2.0
SAMPLE 2	1.289	10.4	0.0
SAMPLE 3	1.289	10.1	0.0
AVERAGE	1.289	10.5	0.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10289	N-219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.264	41.0	-22.0
SAMPLE 2	1.265	57.3	-19.0
SAMPLE 3	1.253	34.1	-22.0
AVERAGE	1.261	44.1	-21.0

TABLE A.8 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10115	BUNA 70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.303	6.0	0.0
SAMPLE 2	1.228	8.2	-3.0
SAMPLE 3	1.291	4.5	-2.0
AVERAGE	1.274	6.2	-1.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10150	BUNA 70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.314	4.4	-2.0
SAMPLE 2	1.217	3.9	3.0
SAMPLE 3	1.307	2.9	3.0
AVERAGE	1.279	3.7	1.3

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10286	BUNA 70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.280	8.0	-6.0
SAMPLE 2	1.205	10.4	-7.0
SAMPLE 3	1.284	8.7	-10.0
AVERAGE	1.256	9.1	-7.7

TABLE A.9 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10306	BUNA 70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.285	13.2	-6.0
SAMPLE 2	1.280	12.8	-9.0
SAMPLE 3	1.290	12.0	-5.0
AVERAGE	1.285	12.7	-6.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10305	BUNA 70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.305	9.7	-8.0
SAMPLE 2	1.298	8.5	-7.0
SAMPLE 3	1.298	9.5	-4.0
AVERAGE	1.300	9.2	-6.3

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10289	BUNA 70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.270	36.7	-4.0
SAMPLE 2	1.274	38.8	-2.0
SAMPLE 3	1.277	34.1	-3.0
AVERAGE	1.280	36.5	-3.0

TABLE A.10 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10115	FS	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.441	3.4	0.0
SAMPLE 2	1.440	3.3	-4.0
SAMPLE 3	1.438	3.3	-3.0
AVERAGE	1.440	3.3	-2.3

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10150	FS	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.483	6.1	-1.0
SAMPLE 2	1.461	3.4	-1.0
SAMPLE 3	1.467	3.3	-3.0
AVERAGE	1.471	4.3	-1.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10246	FS	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.477	13.8	0.0
SAMPLE 2	1.458	11.0	-5.0
SAMPLE 3	1.465	11.5	3.0
AVERAGE	1.467	12.1	-0.7

TABLE A.11 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR DIESEL AND BROADCUT TEST FUELS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10306	FS	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.467	9.7	-7.0
SAMPLE 2	1.453	7.8	-5.0
SAMPLE 3	1.456	7.9	-5.0
AVERAGE	1.459	8.5	-5.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10305	FS	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.477	12.5	-5.0
SAMPLE 2	1.469	13.3	-7.0
SAMPLE 3	1.466	10.3	0.0
AVERAGE	1.471	12.0	-4.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
AL10289	FS	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.467	7.8	-7.0
SAMPLE 2	1.465	8.1	-6.0
SAMPLE 3	1.468	7.2	-7.0
AVERAGE	1.467	7.7	-6.7

TABLE A.12 THERMAL STABILITY DATA FOR BASELINE AND ELASTOMER TOFT TESTS FOR SPECIAL ISOOCTANE AND TOLUENE BLENDS

TOFT TEST	ELASTOMER	SPUN TDR	VISUAL DEPOSIT RATING, ASTM NO.	mmHG	MINUTES
		ISO-OCTANE			
T-55	BASE	3	0	0	150
T-62	VITON	0	0	115	150
T-67	N219-7	1	0	0	150
T-71	BUNA N70	0	0	0	150
T-76	F-SILICONE	0	0	0	150
		70% ISO-OCTANE/ 30% TOLUENE			
T-59	BASE	0	0	0	150
T-63	VITON	1	1	0	150
T-68	N219-7	5	1	125	69
T-73	BUNA N70	0	0	125	113
T-77	F-SILICONE	2	1	0	150
		60% ISO-OCTANE/ 40% TOLUENE			
T-60	BASE	1	0	0	150
T-65	VITON	0	0	0	150
T-69	N219-7	7	3	125	55
T-74	BUNA N70	4	1	125	117
T-78	F-SILICONE	0	0	0	150
		50% ISO-OCTANE/ 50% TOLUENE			
T-61	BASE	3	1	0	150
T-66	VITON	0	0	0	150
T-70	N219-7	7	2	125	108
T-75	BUNA N70	6	1	57	150
T-79	F-SILICONE	0	0	0	150

TABLE A.13 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR SPECIAL ISOOCTANE AND TOLUENE BLENDS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
ISO-OCT.	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.852	0.7	-7.0
SAMPLE 2	1.821	0.7	-6.0
SAMPLE 3	1.829	1.5	-5.0
AVERAGE	1.834	1.0	-6.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
7ISO/3TOL	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.854	2.4	-5.0
SAMPLE 2	1.842	1.7	-5.0
SAMPLE 3	1.849	2.1	-6.0
AVERAGE	1.848	2.0	-5.3

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
6ISO/4TOL	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.857	3.6	-5.0
SAMPLE 2	1.853	3.8	-6.0
SAMPLE 3	1.863	4.8	-4.0
AVERAGE	1.857	4.1	-5.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
5ISO/5TOL	VITON	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.860	6.4	-8.0
SAMPLE 2	1.857	7.4	-8.0
SAMPLE 3	1.865	8.0	-9.0
AVERAGE	1.860	7.3	-8.3

TABLE A.14 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR SPECIAL ISOOCTANE AND TOLUENE BLENDS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
ISO-OCT	N219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.286	1.6	-5.0
SAMPLE 2	1.287	-2.5	-5.0
SAMPLE 3	1.281	-2.0	-6.0
AVERAGE	1.285	-1.0	-5.3

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
7ISO/3TOL	N219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.285	14.7	-5.0
SAMPLE 2	1.190	18.8	-3.0
SAMPLE 3	1.261	13.1	-2.0
AVERAGE	1.245	15.5	-3.3

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
6ISO/4TOL	N219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.215	27.4	-3.0
SAMPLE 2	1.282	18.5	-1.0
SAMPLE 3	1.263	16.9	-4.0
AVERAGE	1.253	20.9	-2.7

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
5ISO/5TOL	N219-7	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.211	17.3	-2.0
SAMPLE 2	1.292	11.0	-5.0
SAMPLE 3	1.294	11.9	-3.0
AVERAGE	1.265	14.1	-3.3

TABLE A.15 POST-TOFT ELASTOMER % VOLUME SWELL AND HARDNESS CHANGE (SHORE A) FOR SPECIAL ISOOCTANE AND TOLUENE BLENDS

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
ISO-OCT	BUNA N70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.298	-0.5	2.0
SAMPLE 2	1.291	-0.8	0.0
SAMPLE 3	1.292	-0.7	1.0
AVERAGE	1.293	-0.7	1.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
7ISO/3TOL	BUNA N70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.292	17.0	-4.0
SAMPLE 2	1.204	19.5	-5.0
SAMPLE 3	1.291	13.7	-3.0
AVERAGE	1.262	16.7	-4.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
6ISO/4TOL	BUNA N70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.290	16.4	-5.0
SAMPLE 2	1.292	13.3	-6.0
SAMPLE 3	1.267	21.6	-4.0
AVERAGE	1.283	17.1	-5.0

FUEL	ELASTOMER	ENVIR	SOAK TIME	SOAK TEMP
5ISO/5TOL	BUNA N70	FREE	2.5HR	150F

WEIGHT & HARDNESS DATA

	SG	%VS(WET)	HC(WET)
SAMPLE 1	1.290	21.5	0.0
SAMPLE 2	1.291	22.2	1.0
SAMPLE 3	1.215	27.7	1.0
AVERAGE	1.265	23.8	0.7

APPENDIX B
DIESEL/FUEL ELASTOMERS EFFECT DATA

APPENDIX B TABLES

TABLE B.1 ELASTOMER SWELL (% Vol. ASTM D471)

AL-9479 Petroleum DF2

Test	Operator 1					Operator 2				
2A	-1.0	-.9	-1.0	-1.0	-.9	-1.3	-.8	-1.4	-1.0	-1.8
2B	-.5	-.5	-.2	.2	.4	2.9	2.1	2.4	2.3	2.7
3A	3.7	4.2	5.0	4.5	4.3	3.4	3.6	4.2	3.8	3.5
3B	5.6	5.4	5.4	4.9	4.6	4.1	3.9	4.5	3.1	2.5
4A	5.4	5.4	6.4	5.1	7.6	5.4	5.4	5.7	5.5	7.1
4B	4.1	5.2	4.9	5.2	5.6	3.6	3.6	3.9	3.9	3.9
5A	4.3	4.2	4.2	4.8	4.4	5.7	4.6	4.7	4.3	3.8
5B	4.6	4.9	5.2	5.0	4.9	4.2	4.2	4.7	4.4	4.4

AL-10150 Paraho-II DFM

Test	Operator 1					Operator 2				
7A	0.0	.4	.3	.6	.8	.0	-1.0	-.1	-.4	-.5
7B	-.5	-.5	-.6	-.9	-.7	-1.2	-1.2	.4	-.9	-1.1
8A	1.0	1.4	1.1	1.0	1.2	-.2	2.9	1.5	1.0	1.1
8B	.9	3.7	3.7	1.9	1.8	2.3	3.3	3.6	2.1	2.3
9A	1.0	1.7	2.7	1.5	2.9	1.3	1.5	2.6	1.3	2.8
9B	.8	.9	2.0	1.1	1.0	0.0	.6	1.7	.6	.8
10A	3.7	3.4	3.8	3.9	3.8	4.6	4.1	4.1	3.8	3.6
10B	3.1	3.2	3.1	4.2	3.6	1.6	3.7	4.2	3.6	4.0

FL-1030-F Sasol-II Diesel

Test	Operator 1					Operator 2				
12A	.4	-.7	-1.2	-.7	-1.1	.1	-.8	-.7	-.7	-.3
12B	-.8	-1.0	-.8	-1.0	-.6	-1.5	-.1	-.2	-.5	-.4
13A	.8	1.7	.5	.4	.8	.5	1.0	-.2	-.4	-.4
13B	1.9	2.1	.9	.8	1.1	2.3	1.8	1.2	.6	.7
14A	1.2	.9	1.4	.3	.2	1.1	1.1	1.5	.3	.6
14B	-.0	-.2	.7	1.9	.9	.3	-.0	.4	1.0	.8
15A	2.6	2.4	2.1	2.3	2.3	2.7	2.4	2.8	2.7	2.8
15B	5.7	5.9	5.4	5.0	5.3	5.0	5.2	5.8	5.0	5.3

TABLE B.2 ELASTOMER HARDNESS CHANGE (SHORE "A"ASTM D2240)

AL-9479 Petroleum DF2

Test	Operator 1					Operator 2				
2A	-6	-4	-5	-5	-3	-6	-8	-6	-7	-4
2B	-4	-1	-1	0	-2	0	0	-2	-2	-7
3A	3	-1	-1	-2	-6	0	5	4	2	-7
3B	1	2	2	5	-7	-2	4	-1	3	1
4A	0	-1	-1	-2	4	0	-1	-5	0	-7
4B	7	0	4	5	3	-5	2	0	3	-2
5A	-5	13	-9	-3	-3	1	14	-1	-2	-1
5B	-3	-7	2	-7	-2	-3	4	16	9	-2

AL-10150 Paraho-II DFM

Test	Operator 1					Operator 2				
7A	-5	-9	-5	-3	-12	-9	10	1	-4	-1
7B	1	-3	-5	6	-3	5	4	-2	-1	0
8A	6	2	3	5	2	4	-4	3	6	9
8B	7	8	2	4	4	1	1	0	2	2
9A	20	-2	0	5	5	9	4	2	5	2
9B	-4	3	7	8	2	0	4	-2	2	0
10A	-11	-6	-2	-3	-3	-5	-16	-16	0	4
10B	-3	-10	-3	0	-13	-8	-1	1	-4	-5

FL-1030-F Sasol-II Diesel

Test	Operator 1					Operator 2				
12A	-3	-1	0	-8	-8	-10	-2	-3	-6	3
12B	-17	-5	0	3	-13	7	-3	1	2	5
13A	4	7	7	14	7	0	5	8	3	8
13B	7	5	5	4	-1	6	4	1	5	7
14A	2	1	2	5	7	0	0	-4	0	3
14B	2	6	3	3	9	6	0	8	3	4
15A	-2	7	-12	-3	-7	-3	3	-2	2	8
15B	-1	3	-2	6	3	-1	-4	2	-1	5

TABLE B.3 THERMAL STABILITY (MODIFIED ASTM D3241,660C SUMP)

AL-9479 Petroleum DF2

Test	Spun TDR				in Hg
	OP1	OP2	OP3	OP4	
1A	0	0	0	0	125
1B	1	1	3	3	50
2A	0	0	1	1	32
2B	1	2	3	3	18
3A	3	4	3	4	125
3B	4	3	3	3	85
4A	10	13	13	12	70
4B	13	12	12	12	125
5A	4	4	4	3	125
5B	3	3	3	2	25

AL-10150 Paraho-II DFM

Test	Spun TDR				in Hg
	OP1	OP2	OP3	OP4	
6A	0	0	0	0	0
6B	0	0	0	0	5
7A	3	2	2	2	0
7B	0	0	0	0	0
8A	17	17	19	18	125
8B	10	10	10	10	125
9A	4	4	7	7	125
9B	9	9	11	10	125
10A	0	0	0	0	3
10B	0	0	0	0	0

FL-1030-F Sasol-II Diesel

Test	Spun TDR				in Hg
	OP1	OP2	OP3	OP4	
11A	26	25	27	27	0
11B	27	27	28	27	0
12A	28	28	28	28	8
12B	34	33	33	33	0
13A	10	10	10	10	0
13B	15	14	17	17	13
14A	14	14	16	15	0
14B	11	10	10	10	0
15A	30	30	30	30	0
15B	33	33	33	33	0

TABLE B.4 ANALYSIS OF VARIANCE-SWELL

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
	MEAN	95.42486	1	95.42486	262.59	.0000
	E	58.39548	3	19.46516	53.56	.0000
	F	23.14083	2	11.57041	31.84	.0000
	EF	13.53713	6	2.25619	6.21	.0037
1	ERROR	4.36078	12	.36340		

CASE	ELAST	FUEL	PREDICTD	RESIDUAL
1	VITON	REF	-.61000	-.49000
2	VITON	SHALE	-.36000	.36200
3	VITON	COAL	-.62600	.05800
4	N219	REF	4.21250	-.19550
5	N219	SHALE	1.87850	-.68550
6	N219	COAL	.90100	-.42900
7	BUNA	REF	5.14600	.75900
8	BUNA	SHALE	1.44200	.48300
9	BUNA	COAL	.73150	.13150
10	FLSI	REF	4.57200	-.07400
11	FLSI	SHALE	3.65400	.22300
12	FLSI	COAL	2.98650	-.48150
13	VITON	REF	-.61000	.49000
14	VITON	SHALE	-.36000	-.36200
15	VITON	COAL	-.62600	-.05800
16	N219	REF	4.21250	.19550
17	N219	SHALE	1.87850	.68550
18	N219	COAL	.90100	.42900
19	BUNA	REF	5.14600	-.75900
20	BUNA	SHALE	1.44200	-.48300
21	BUNA	COAL	.73150	-.13150
22	FLSI	REF	4.57200	.07400
23	FLSI	SHALE	3.65400	-.22300
24	FLSI	COAL	2.98650	.48150

ERROR TERM	SUM OF SQUARES	RECOMPUTED FROM RESIDUALS	RELATIVE ERROR
1	4.36078	4.36078	-.00000

TABLE B.5 ANALYSIS OF VARIANCE-HARDNESS

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
	MEAN	1.21500	1	1.21500	.43	.5223
	E	141.55167	3	47.18389	16.87	.0001
	F	17.15250	2	8.57625	3.07	.0840
	EF	65.69083	6	10.94847	3.91	.0212
1	ERROR	33.57000	12	2.79750		

CASE	ELAST	FUEL	PREDICTD	RESIDUAL
1	VITON	REF	-3.65000	-1.75000
2	VITON	SHALE	-1.75000	-1.95000
3	VITON	COAL	-2.90000	-.90000
4	N219	REF	.25000	-.55000
5	N219	SHALE	3.35000	.25000
6	N219	COAL	5.30000	1.00000
7	BUNA	REF	.20000	-1.50000
8	BUNA	SHALE	3.50000	1.50000
9	BUNA	COAL	3.00000	-1.40000
10	FLSI	REF	.55000	-.15000
11	FLSI	SHALE	-5.20000	-.60000
12	FLSI	COAL	.05000	-.95000
13	VITON	REF	-3.65000	1.75000
14	VITON	SHALE	-1.75000	1.95000
15	VITON	COAL	-2.90000	.90000
16	N219	REF	.25000	.55000
17	N219	SHALE	3.35000	-.25000
18	N219	COAL	5.30000	-1.00000
19	BUNA	REF	.20000	1.50000
20	BUNA	SHALE	3.50000	-1.50000
21	BUNA	COAL	3.00000	1.40000
22	FLSI	REF	.55000	.15000
23	FLSI	SHALE	-5.20000	.60000
24	FLSI	COAL	.05000	.95000

ERROR TERM	SUM OF SQUARES	RECOMPUTED FROM RESIDUALS	RELATIVE ERROR
1	33.57000	33.57000	.00000

TABLE B.6 ANALYSIS OF VARIANCE-TDR

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
	MEAN	3330.64033	1	3330.64033	536.81	.0000
	E	19.68217	4	4.92054	.79	.5478
	F	2274.85067	2	1137.42533	183.32	.0000
	EF	1163.79433	8	145.47429	23.45	.0000
1	ERROR	93.06750	15	6.20450		

CASE	ELAST	FUEL	PREDICTD	RESIDUAL
1	NONE	REF	1.00000	-1.00000
2	NONE	REF	1.00000	1.00000
3	VITON	REF	1.37500	-.87500
4	VITON	REF	1.37500	.87500
5	N219	REF	3.30000	.05000
6	N219	REF	3.30000	-.05000
7	BUNA	REF	12.12500	-.12500
8	BUNA	REF	12.12500	.12500
9	FLSI	REF	3.25000	.50000
10	FLSI	REF	3.25000	-.50000
11	NONE	SHALE	.00000	-.00000
12	NONE	SHALE	.00000	-.00000
13	VITON	SHALE	1.12500	1.12500
14	VITON	SHALE	1.12500	-1.12500
15	N219	SHALE	14.00000	4.00000
16	N219	SHALE	14.00000	-4.00000
17	BUNA	SHALE	7.62500	-2.12500
18	BUNA	SHALE	7.62500	2.12500
19	FLSI	SHALE	.00000	-.00000
20	FLSI	SHALE	.00000	-.00000
21	NONE	COAL	26.75000	-.50000
22	NONE	COAL	26.75000	.50000
23	VITON	COAL	30.62500	-2.62500
24	VITON	COAL	30.62500	2.62500
25	N219	COAL	12.87500	-2.87500
26	N219	COAL	12.87500	2.87500
27	BUNA	COAL	12.50000	2.25000
28	BUNA	COAL	12.50000	-2.25000
29	FLSI	COAL	31.50000	-1.50000
30	FLSI	COAL	31.50000	1.50000

ERROR TERM	SUM OF SQUARES	RECOMPUTED FROM RESIDUALS	RELATIVE ERROR
1	93.06750	93.06750	-.00000

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CHIEF OF NAVAL RESEARCH
ATTN: CODE 473 (DR R MILLER) 1
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